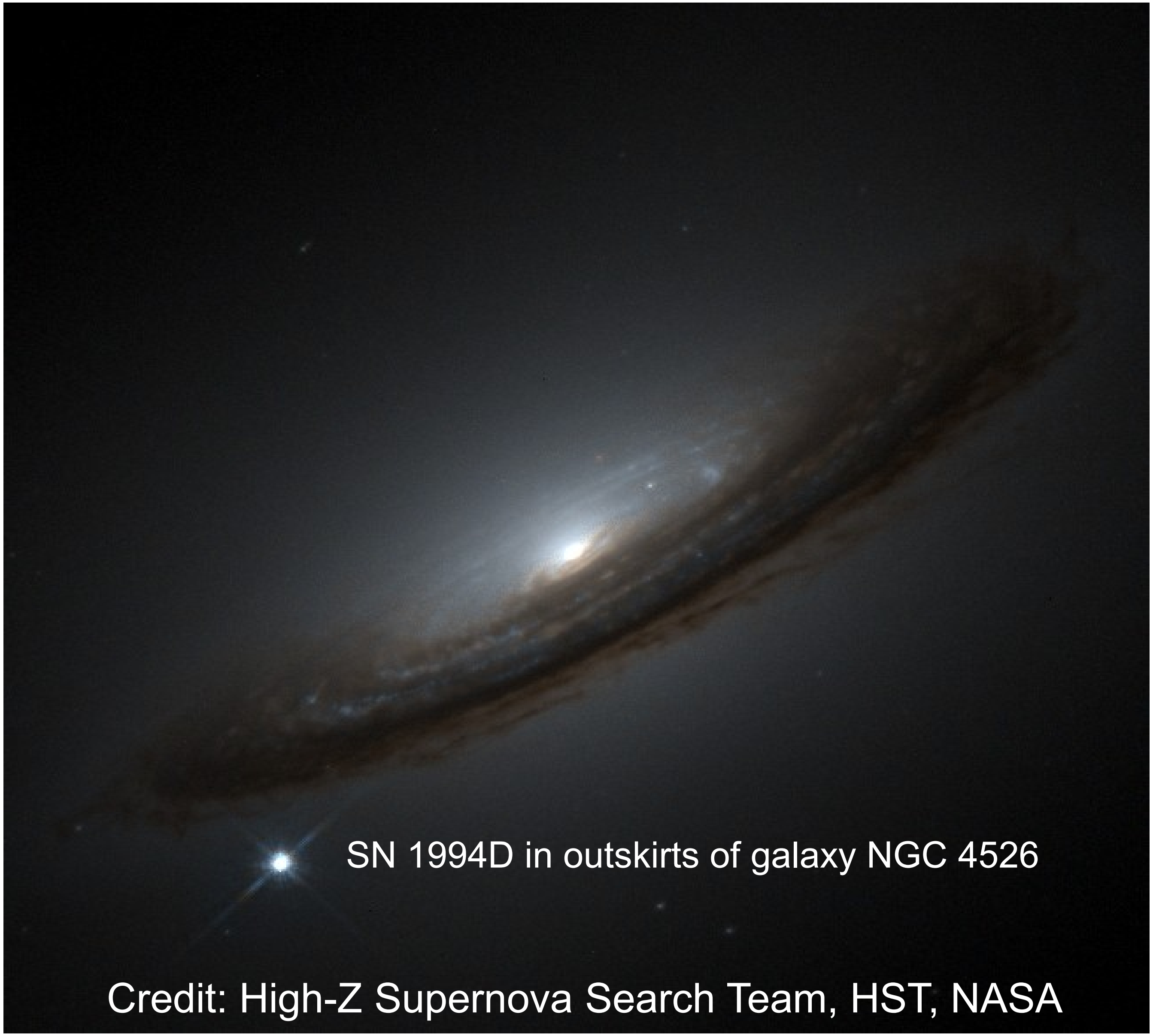
# Supernova Cosmology

Steve Kuhlmann (major contributions Rahul Biswas)
Argonne National Laboratory

Santa Fe Cosmology Workshop 2012


SN 1994D in outskirts of galaxy NGC 4526
Credit: High-Z Supernova Search Team, HST, NASA

- Type Ia SNe Light Curves
- SALT2 Light Curve Model Basics
- Union 2.1 Sample (SCP) plots not in their paper or their web page
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- Calibration
- Type Ia brightness correlations with host galaxy properties
- Type Ia Progenitor Systems
- Dust/Color
- UV problem
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- Dark Energy Survey SNe Cosmology optimization
- Core Collapse SNe contamination of photometric samples
- Standardization details, Peculiars, Spectral Distance Indicators, Type Ia explosion models, IR, Twins... (not covered in this talk)

- Using Type Ia supernova only

- Assumed coming from ~1 $M_{solar}$ white dwarf in binary system with accretion from partner that pushes over Chandrasehkar limit of ~1.44 $M_{solar}$ and causes supernova.

- Absolute brightness M correlated with length of light curve (stretch) and can be “standarized” to about 0.1 magnitudes.

- Measure 3 things: 1) Observed brightness m, 2) Absolute brightness M, and 3) redshift. Distance modulus $\mu$= m-M

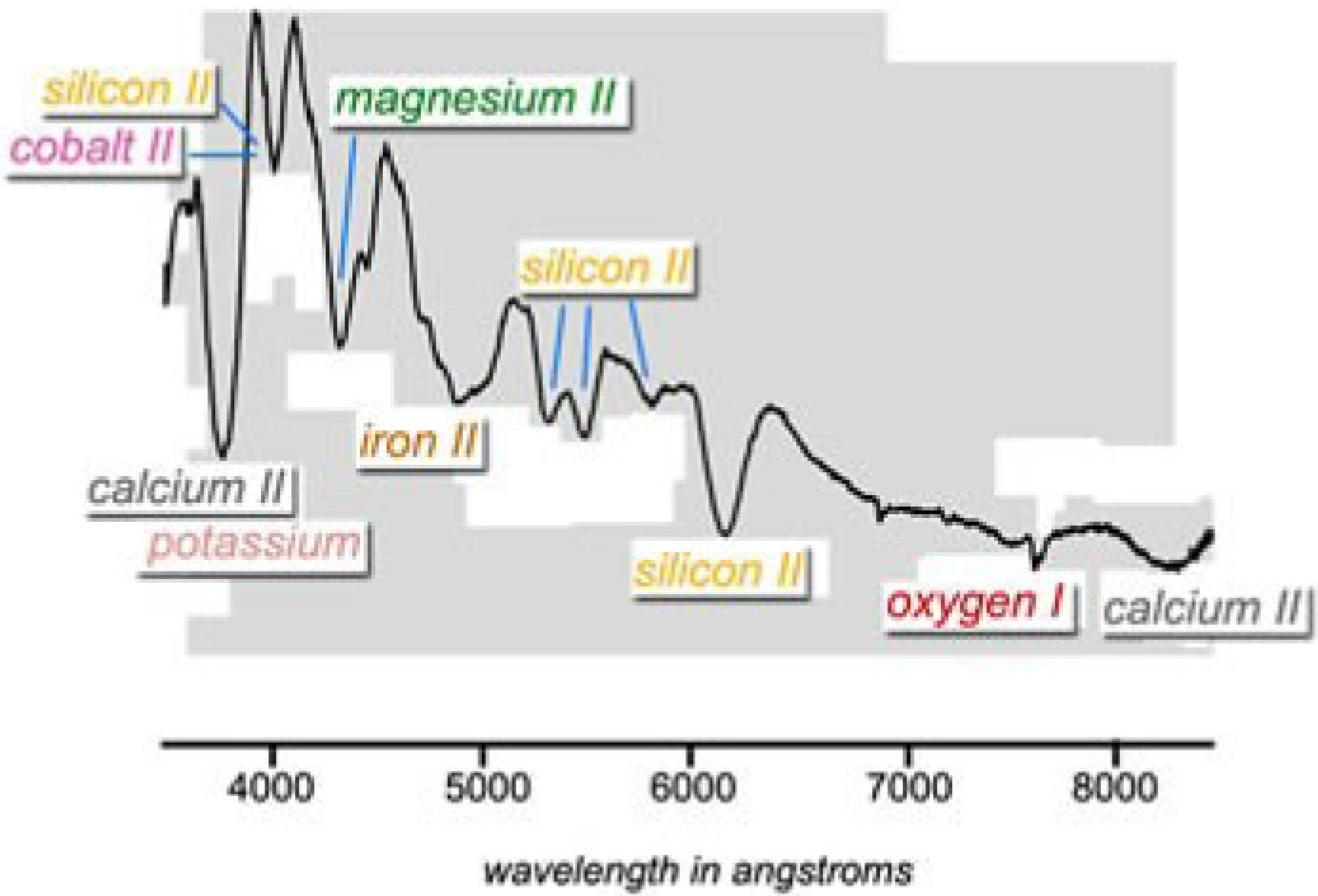
- Distance modulus vs redshift (Hubble diagram) predicted by cosmology and can be compared to data.

# Historical Review of Accelerated Expansion Discovery

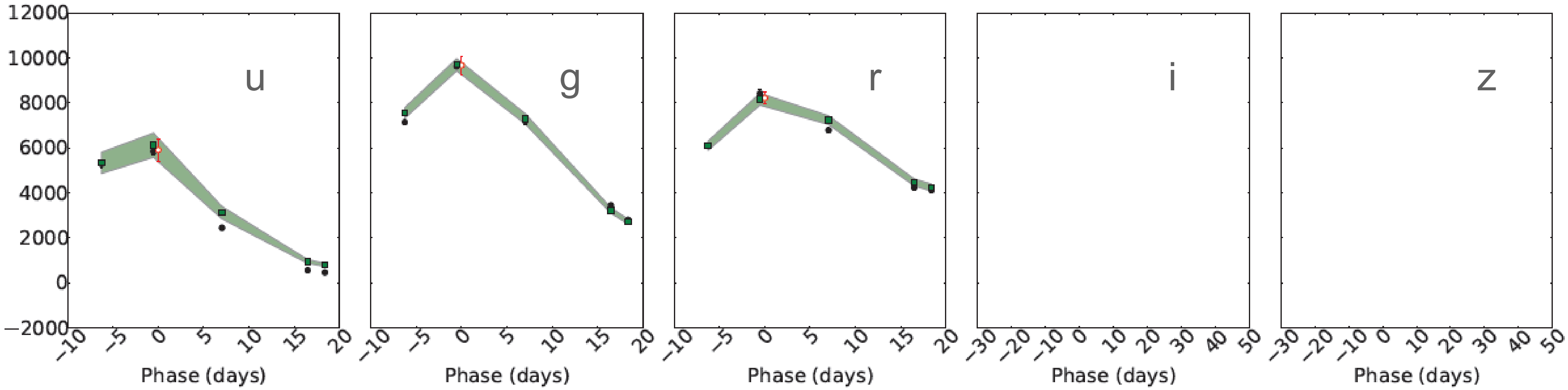
http://www.youtube.com/watch?v=SZ8AuD1tM5g

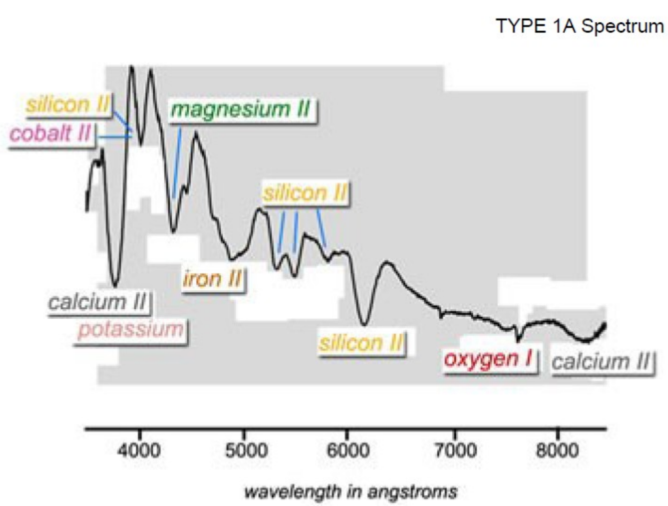
## Redshift: Assume Supernova redshift determined by full spectra of SN or its host galaxy and is known precisely.

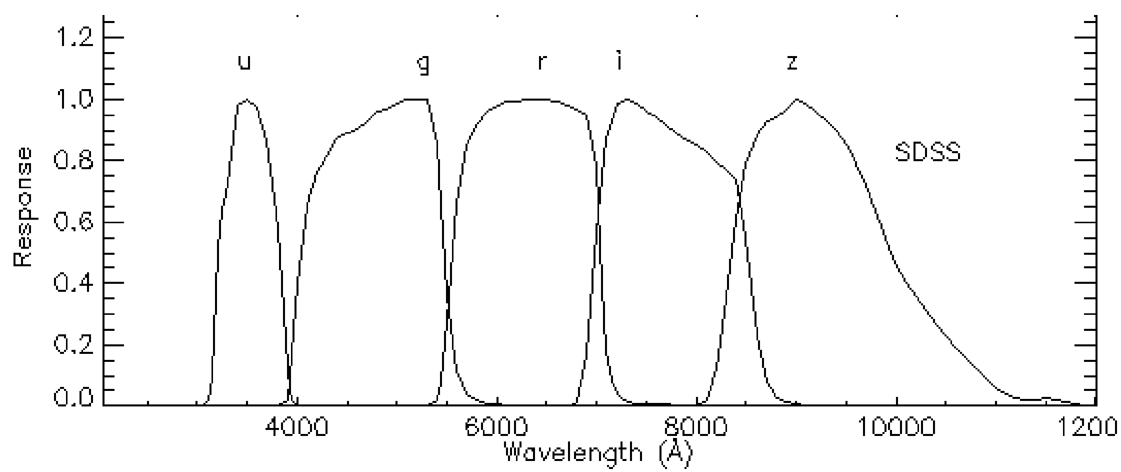
TYPE 1A Spectrum



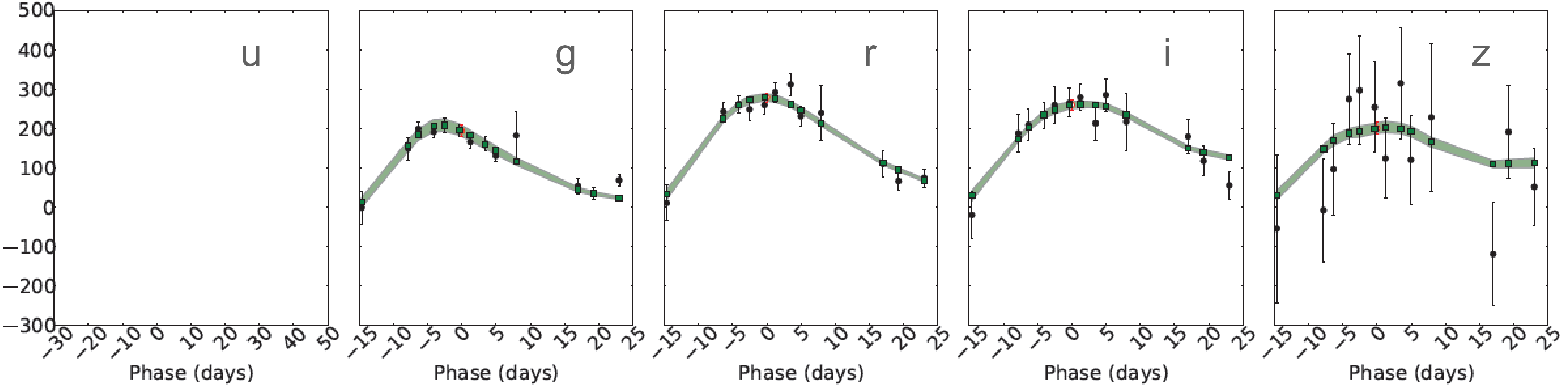
# Example SDSS Type Ia light curves (data z=0.05)



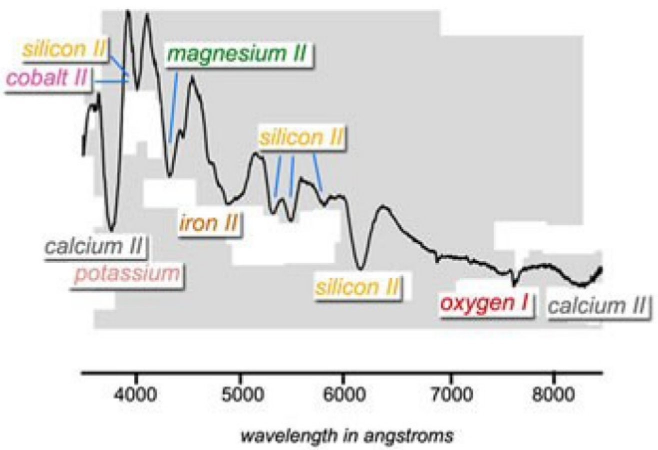



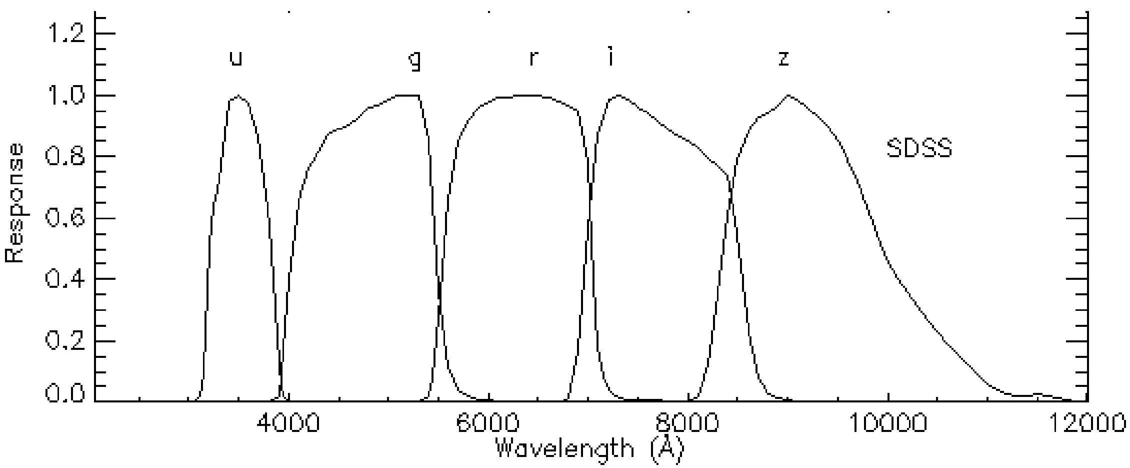



# Example SDSS Type Ia light curves (data z=0.33)

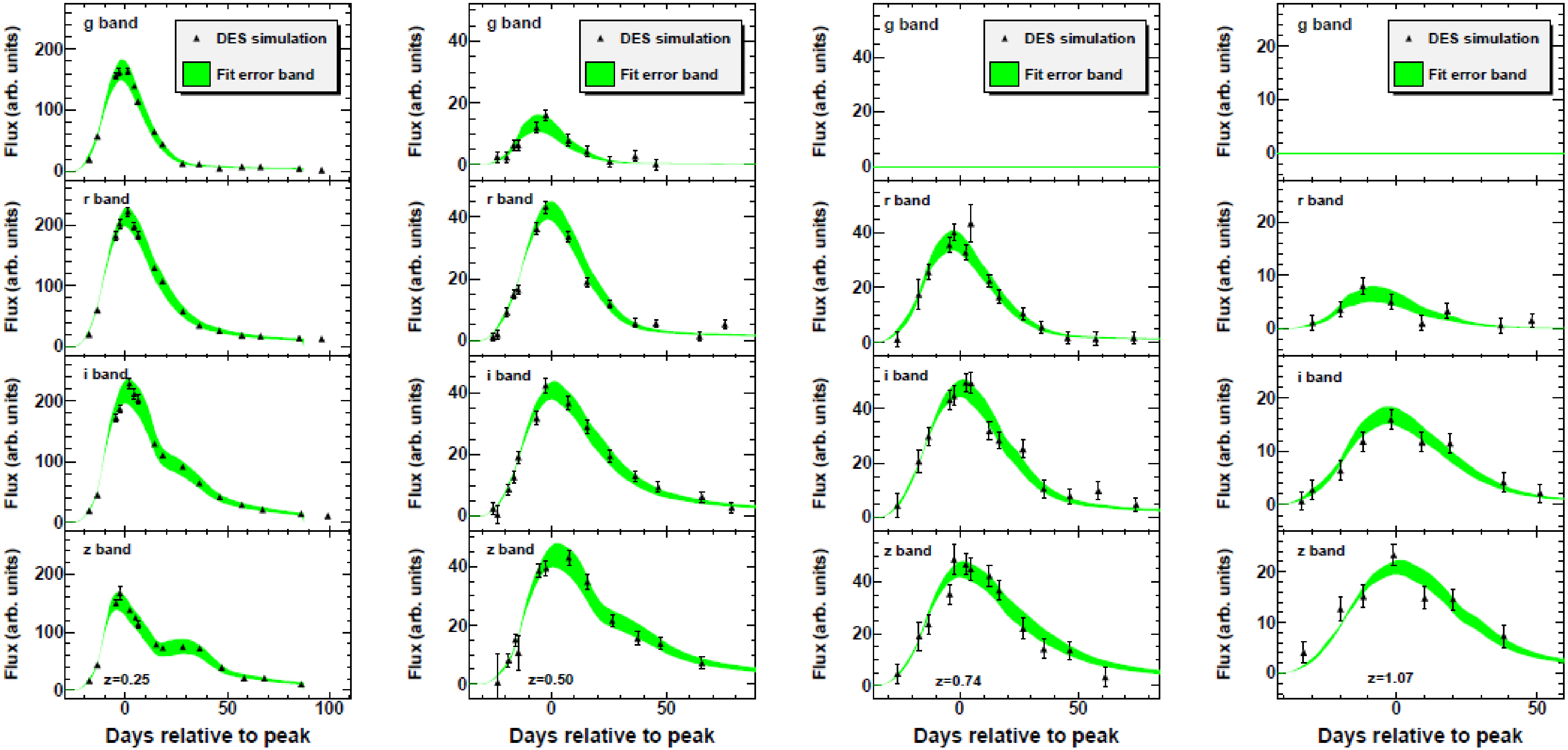



TYPE 1A Spectrum



# Example Dark Energy Survey Simulated Type Ia light curves (first light this fall)




z=0.25 z=0.5 z=0.74 z=1.07

# Some Popular Light Curve Models

Simple 1-parameter stretch (early model)

MLCS2k2 (Jha et al. 2007)

SALT2 (Guy et al. 2007) (used by Union 2 and emphasis of Rahul's work and this talk)

SIFTO (Conley et al. 2008, SALT-like)

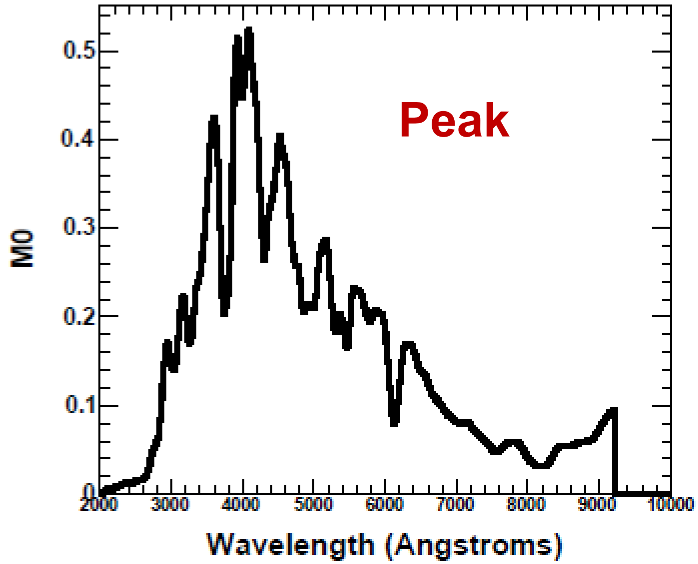
# SALT2 Light Curve Model Basics

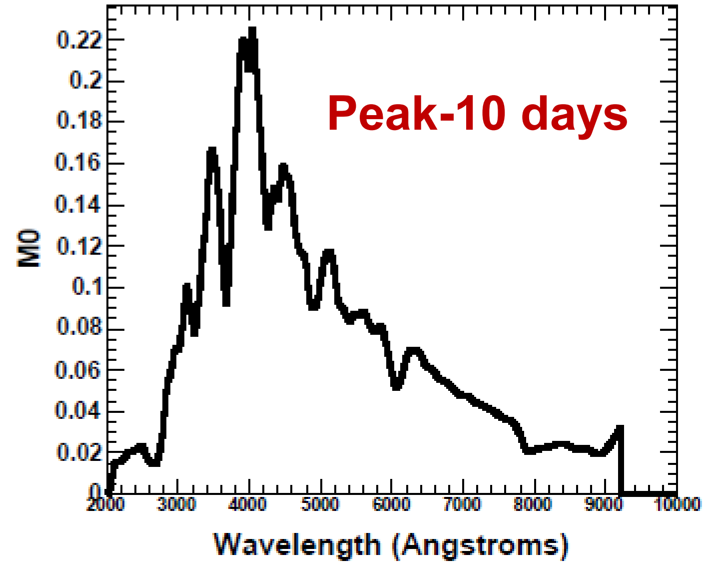
$$\mathrm{Flux}(p,\lambda) = x0*(M0(p,\lambda) + x1*M1(p,\lambda))*\exp(c*CL(\lambda))$$

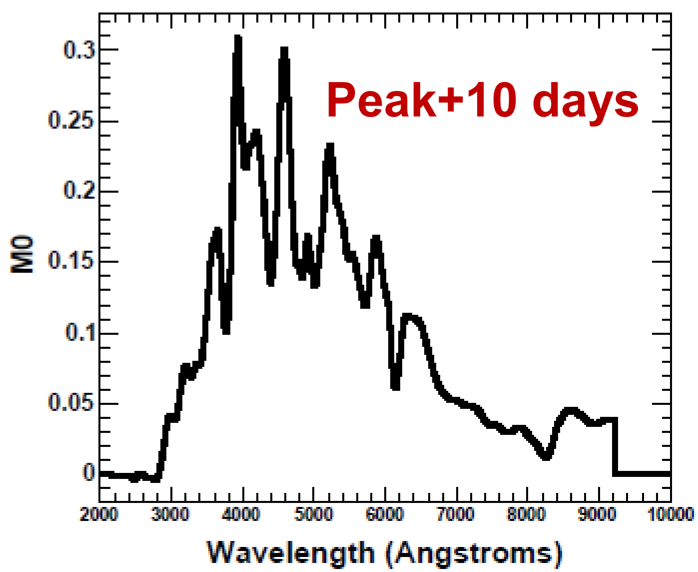
M0, M1, CL   fitted to previous training set (p is phase)

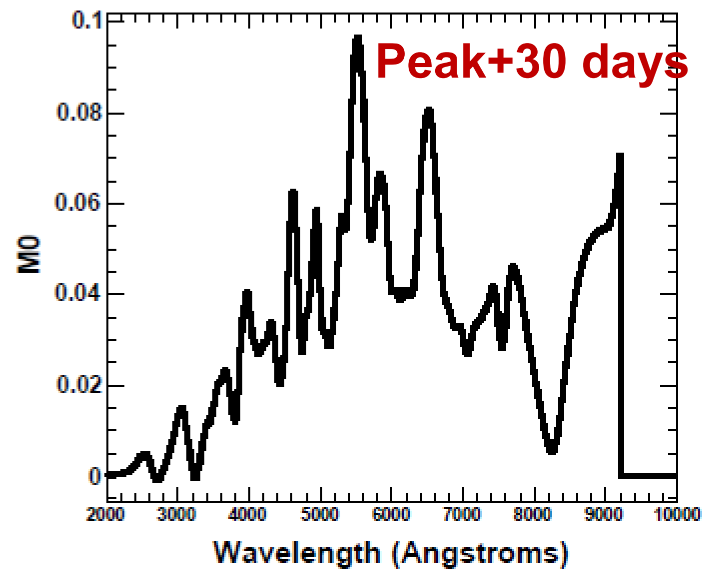
x0, x1, c   fit to new individual SN light curves

Redshift the Flux and integrate over detector filter bands to fit to data


Peak
M0
0.5
0.4
0.3
0.2
0.1
0
2000 3000 4000 5000 6000 7000 8000 9000 10000
Wavelength (Angstroms)


Peak-10 days
M0
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2000 3000 4000 5000 6000 7000 8000 9000 10000
Wavelength (Angstroms)


Peak+10 days
M0
0.3
0.25
0.2
0.15
0.1
0.05
0
2000 3000 4000 5000 6000 7000 8000 9000 10000
Wavelength (Angstroms)


Peak+30 days
M0
0.1
0.08
0.06
0.04
0.02
0
2000 3000 4000 5000 6000 7000 8000 9000 10000
Wavelength (Angstroms)

# SALT2 Light Curve Model Basics

$\mu = m - M + \alpha * x1 + \beta * c$

Distance modulus determined in a combined fit to all SNe at once for M, $\alpha$, $\beta$ and the cosmology parameters.

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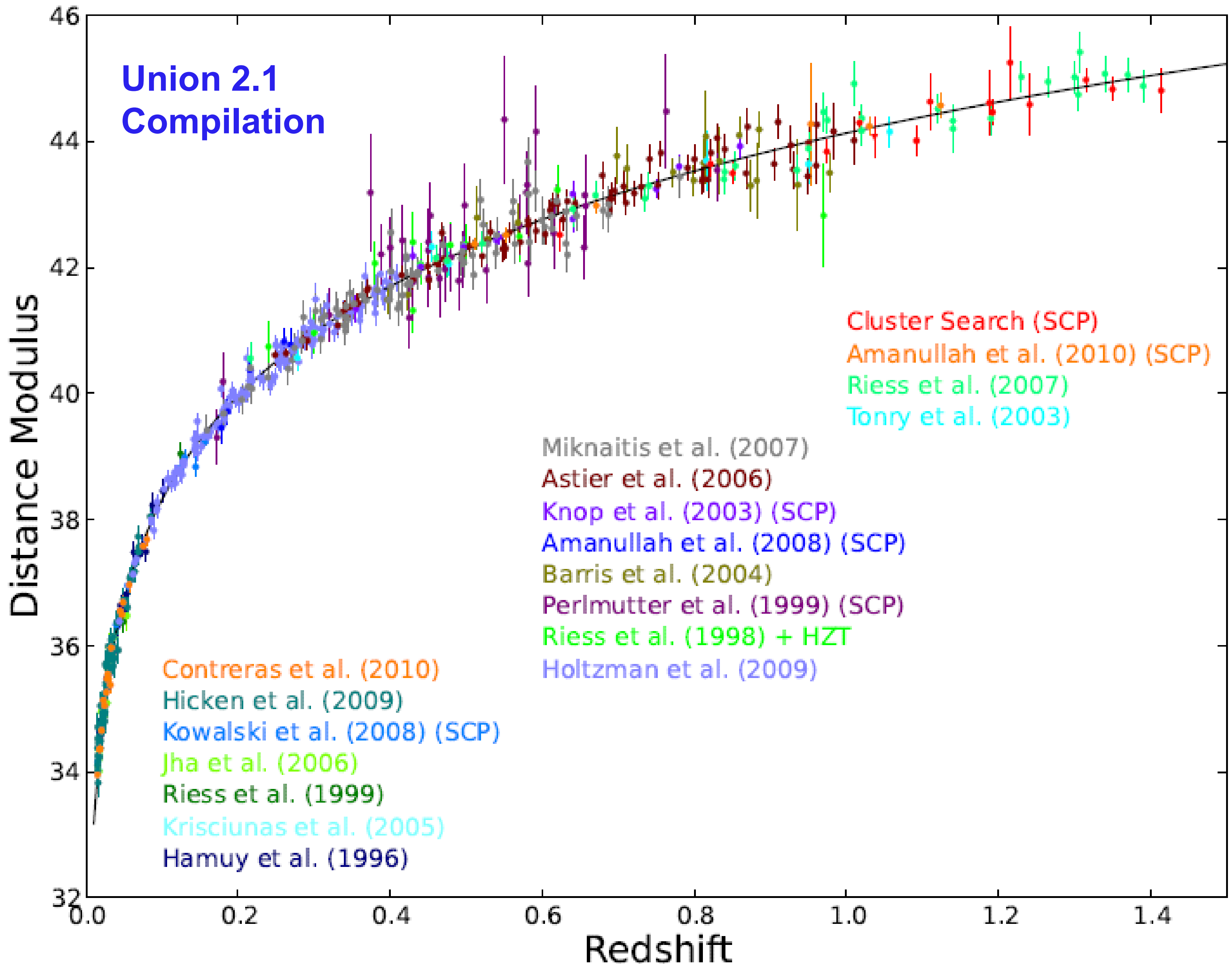
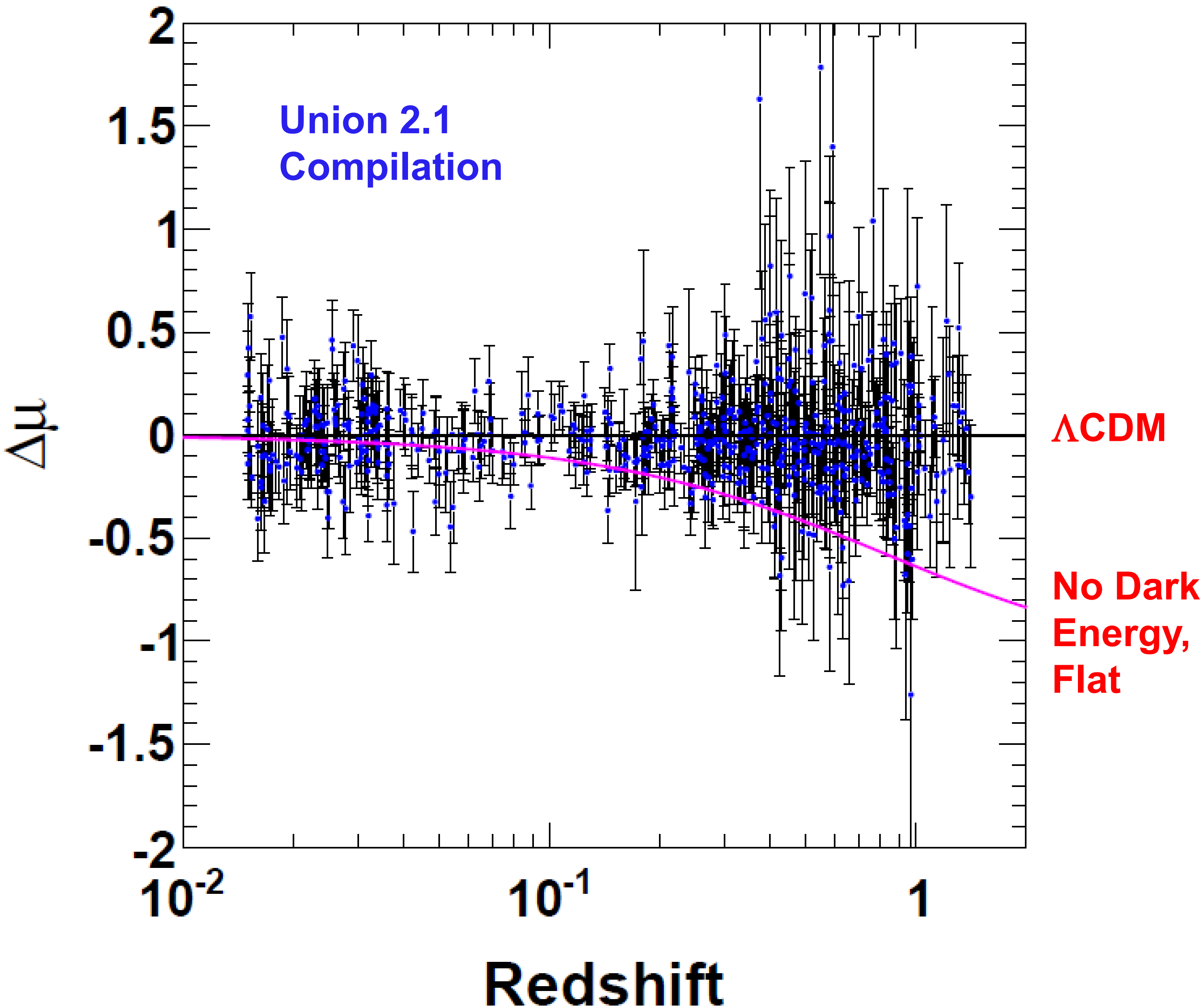
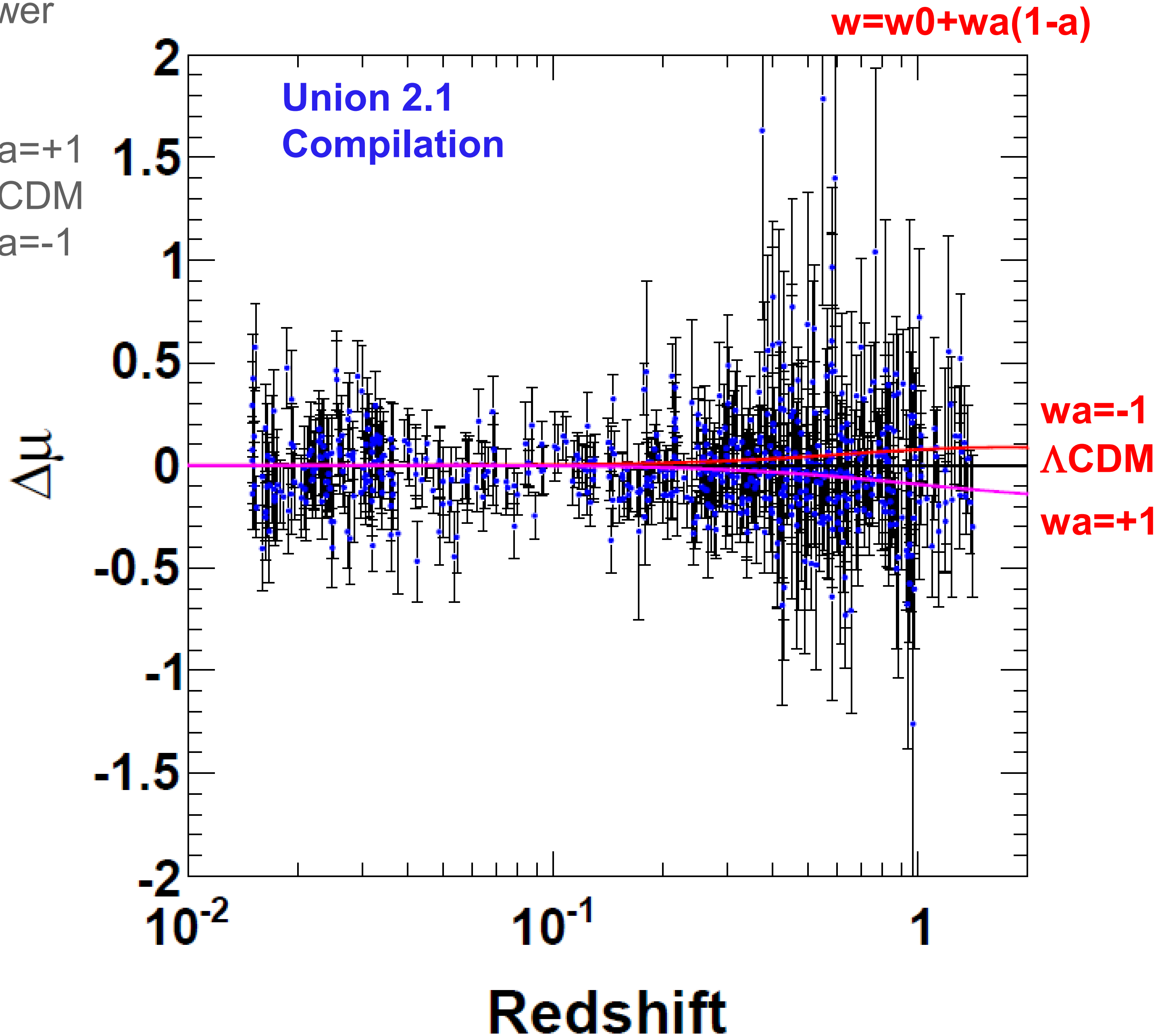
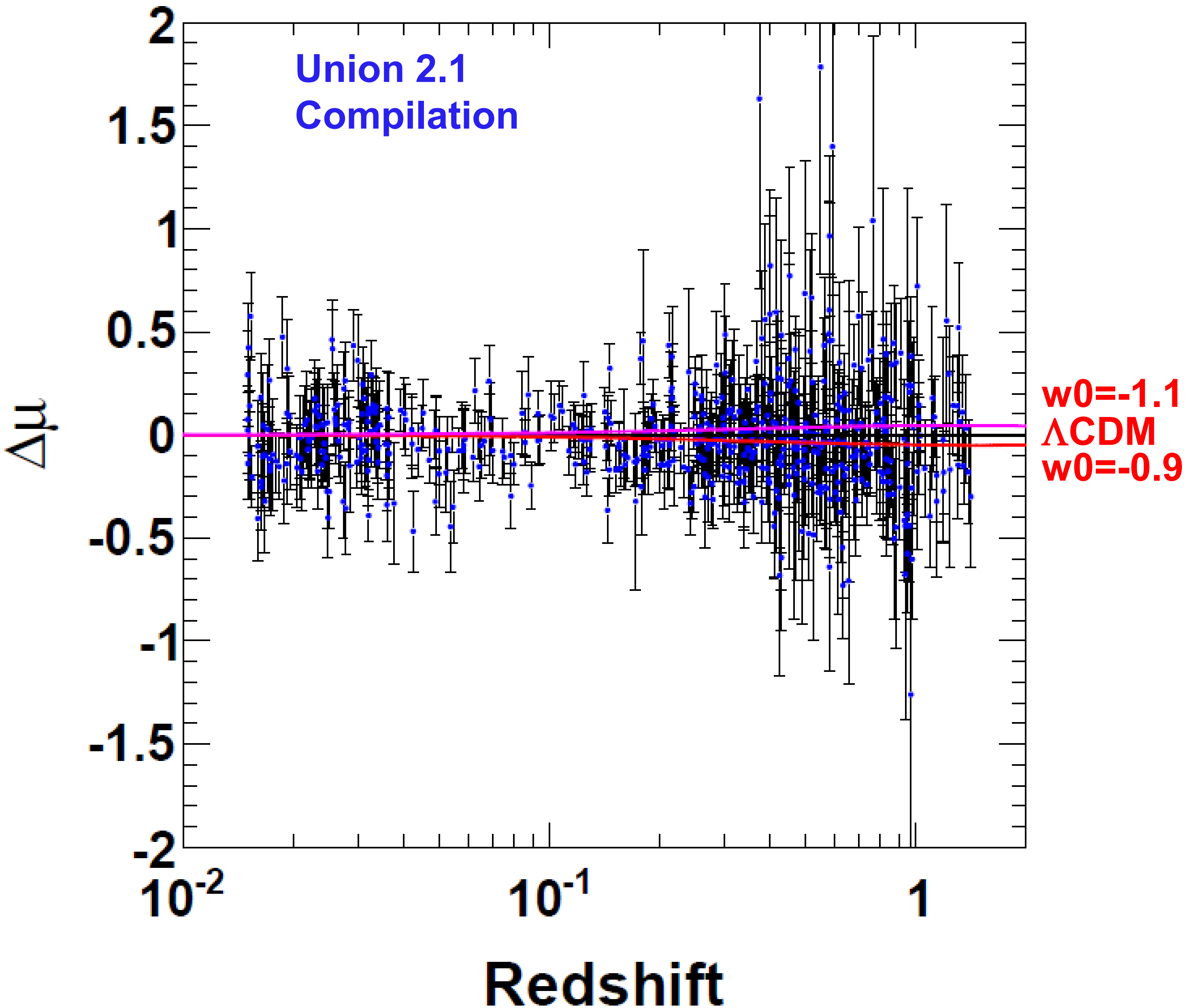

Union 2.1
Compilation
Distance Modulus
Redshift
46
44
42
40
38
36
34
32
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Cluster Search (SCP)
Amanullah et al. (2010) (SCP)
Riess et al. (2007)
Tonry et al. (2003)
Miknaitis et al. (2007)
Astier et al. (2006)
Knop et al. (2003) (SCP)
Amanullah et al. (2008) (SCP)
Barris et al. (2004)
Perlmutter et al. (1999) (SCP)
Riess et al. (1998) + HZT
Holtzman et al. (2009)
Contreras et al. (2010)
Hicken et al. (2009)
Kowalski et al. (2008) (SCP)
Jha et al. (2006)
Riess et al. (1999)
Krisciunas et al. (2005)
Hamuy et al. (1996)

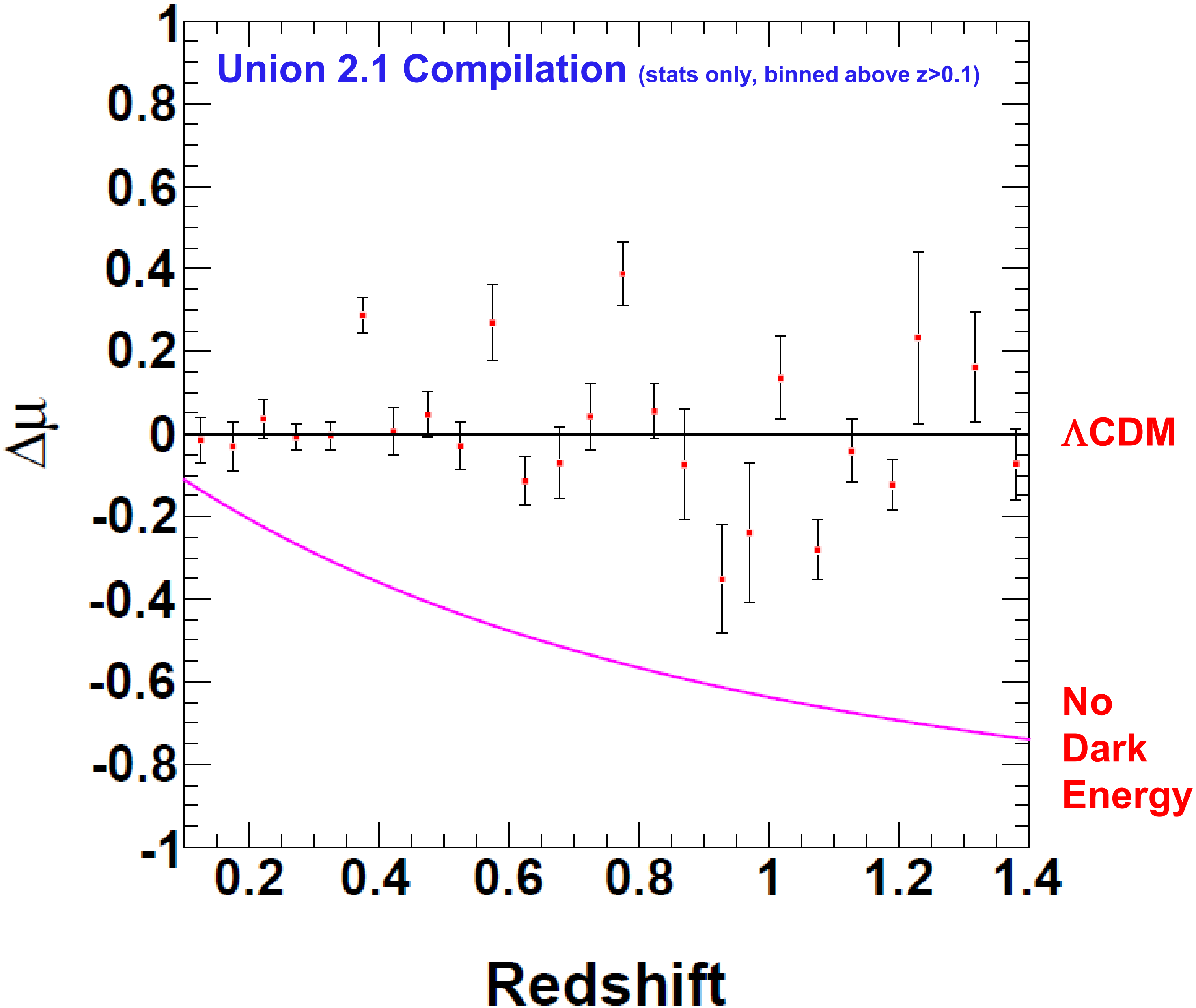

Union 2.1
Compilation
ΛCDM
No Dark
Energy,
Flat
Δμ
Redshift
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
10^-2
10^-1
1

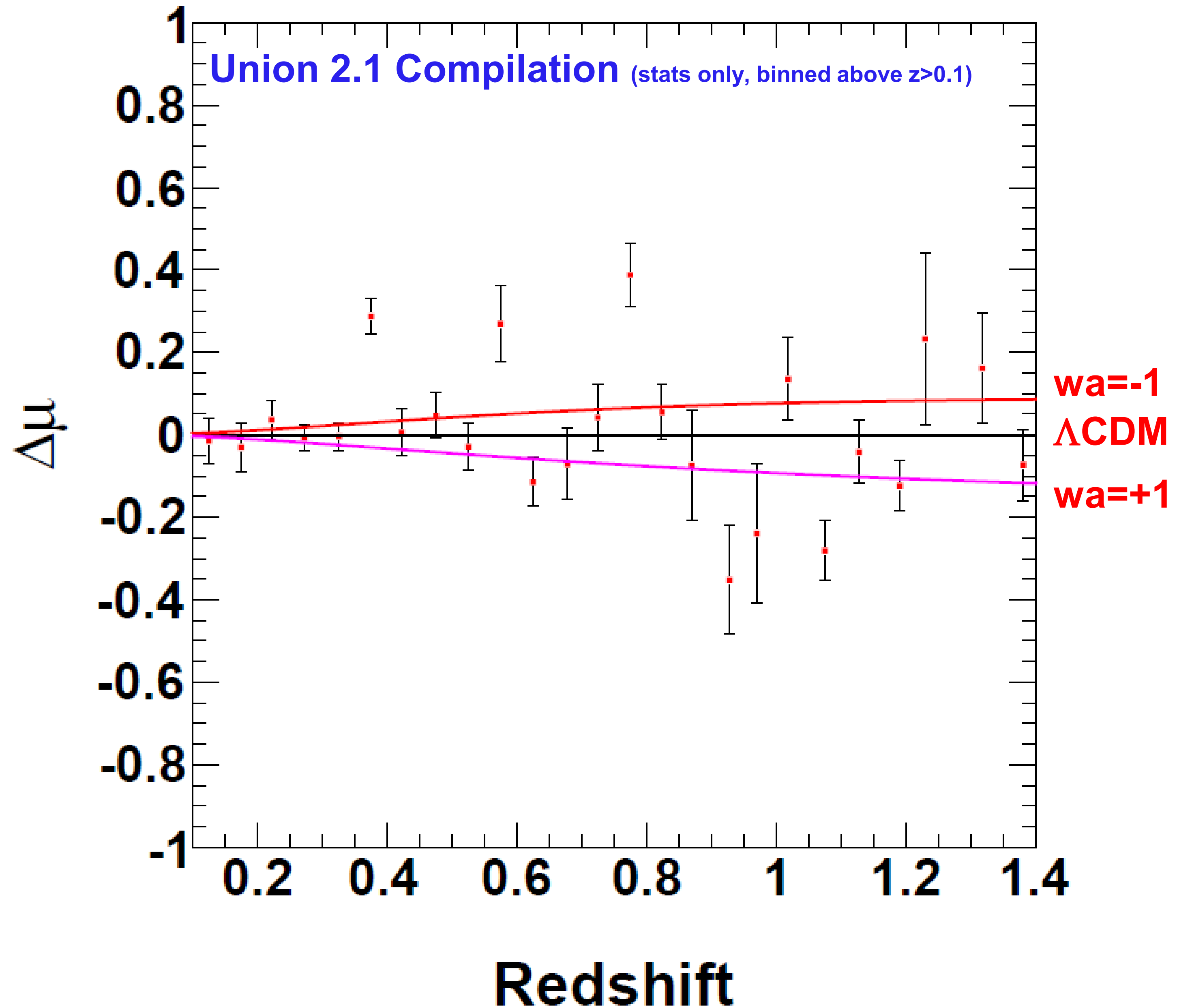
Statistical power not enough:

Chisq=572 wa=+1
Chisq=575 ΛCDM
Chisq=614 wa=-1




Union 2.1
Compilation
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Δμ
10-2
10-1
1
Redshift
w0=-1.1
ΛCDM
w0=-0.9

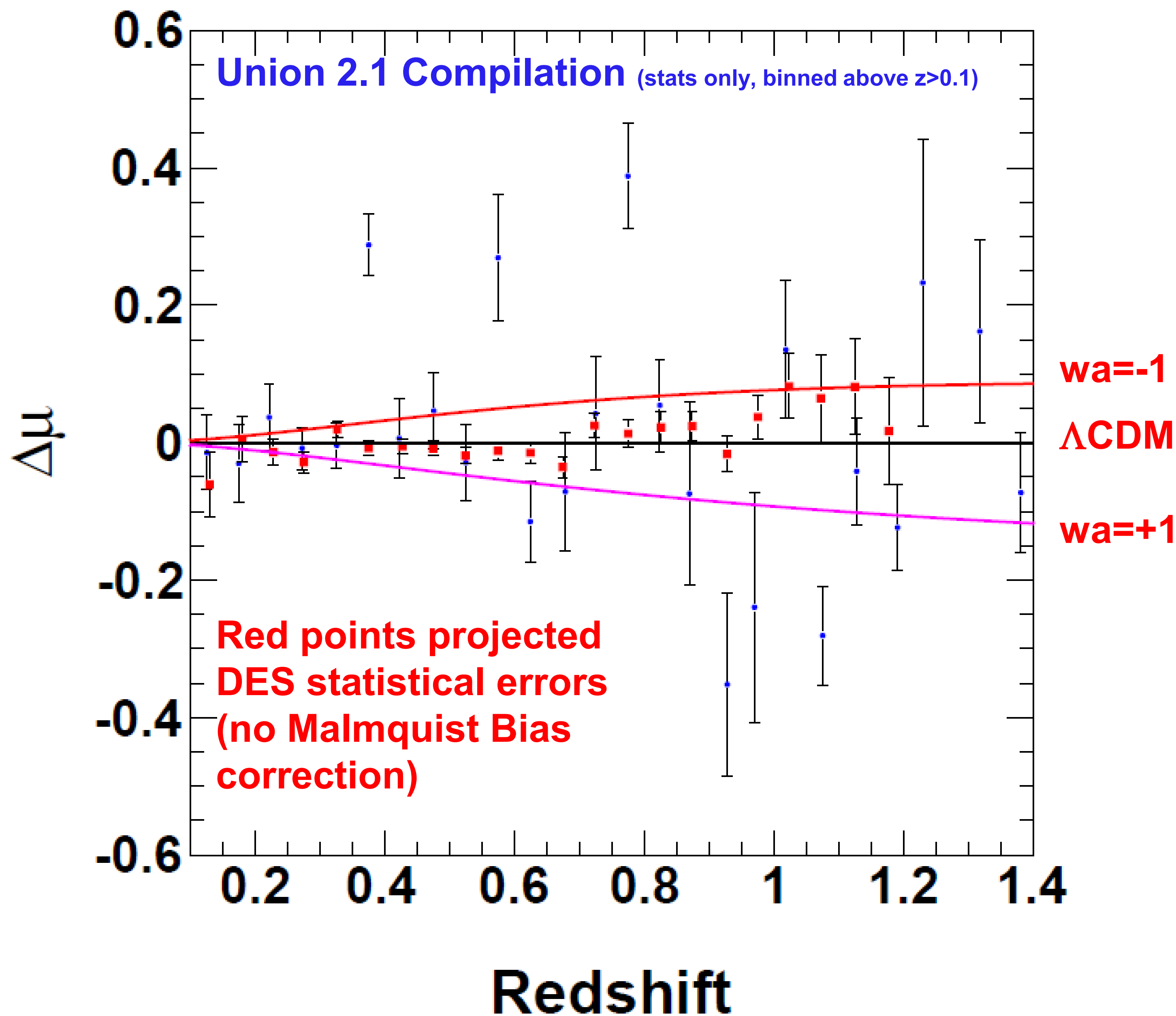

Union 2.1 Compilation (stats only, binned above z>0.1)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
$\Delta\mu$
0.2
0.4
0.6
0.8
1
1.2
1.4
Redshift
ΛCDM
No Dark Energy



Union 2.1 Compilation (stats only, binned above z>0.1)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Δμ
0.2
0.4
0.6
0.8
1
1.2
1.4
wa=-1
ΛCDM
wa=+1
Redshift

All including Union 2.1 (including SN systematics) + CMB + BAO + H0

| Prior | w0 | wa |
|---|---|---|
| wCDM | -1.013±0.07 | Fixed at 0 |
| wCDM allow curvature | -1.003±0.093 | Fixed at 0 |
| $w_z$ CDM, no curvature, allow w vary with z | -1.046±0.175 | 0.14±0.68 |
| $w_z$ CDM, allow curvature and w vary with z | -1.198±0.11 | 1.19±0.13 |



Union 2.1 Compilation (stats only, binned above z>0.1)
Red points projected
DES statistical errors
(no Malmquist Bias
correction)
wa=-1
ΛCDM
wa=+1
Δμ
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0.2
0.4
0.6
0.8
1
1.2
1.4
Redshift

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# Union 2.1 SN systematics

Calibration

| Source | Error on Constant $w$ |
|---|---|
| Vega | 0.033 |
| All Instrument Calibration | 0.030 |
| (ACS Zeropoints) | 0.003 |
| (ACS Filter Shift) | 0.007 |
| (NICMOS Zeropoints) | 0.007 |
| Malmquist Bias | 0.020 |
| Color Correction | 0.020 |
| Mass Correction | 0.016 |
| Contamination | 0.016 |
| Intergalactic Extinction | 0.013 |
| Galactic Extinction Normalization | 0.010 |
| Rest-Frame $U$-Band Calibration | 0.009 |
| Lightcurve Shape | 0.006 |
| *Quadrature Sum of Errors/ Sum of Area (not used)* | *0.061* |
| Summed in Covariance Matrix | 0.048 |

# Union 2.1 instrumental systematics

| Source | Band | Uncertainty |
|---|---|---|
| HST | WFPC2 | 0.02 |
| | ACS F850LP | 0.01 |
| | ACS F775W | 0.01 |
| | ACS F606W | 0.01 |
| | ACS F850LP | 94 Å |
| | ACS F775W | 57 Å |
| | ACS F606W | 27 Å |
| | NICMOS J | 0.024 |
| | NICMOS H | 0.06 |
| SNLS | $g, r, i$ | 0.01 |
| | $z$ | 0.03 |
| ESSENCE | $R, I$ | 0.014 |
| SDSS | $u$ | 0.014 |
| | $g, r, i$ | 0.009 |
| | $z$ | 0.010 |
| SCP: Amanullah et al. (2010) | $R, I$ | 0.03 |
| | $J$ | 0.02 |
| Other | $U$-band | 0.04 |
| | Other Band | 0.02 |

- Having a single experiment that spans almost all the redshift range with good statistics, like DES, will help.
- Still need a low-z anchor and have to cross-calibrate.
- More collaboration between groups, overlapping fields, etc.
- Spend more money, more people, more dedicated calibration cameras and telescopes, etc.

## DES Photometric Requirements

- Absolute Color: 0.5% (*g-r*, *r-i*, *i-z*); 1% (*z-Y*) [averaged over 100 objects scattered over FP]
- Absolute Flux: 0.5% in *i*-band (relative to BD+17 4708)

# Absolute spectral references

- Vega, BD+17, HST standards typically used

- DA white dwarfs (stable hydrogen absorption lines only) are a popular choice, but only a few currently available

- Large effort (in DES and elsewhere) to identify DA white dwarfs and increase the numbers by x10 or more

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# Union 2.1 SN systematics

**Type Ia brightness correlations with host galaxy and Type Ia Progenitors**

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# Type Ia Supernova review again:

- **Normal star burns out hydrogen and helium, creating ~1 solar mass carbon-oxygen white dwarf with few % other elements (metallicity). (% depends on history of star and its galaxy)**

- **Accretion from binary companion increases white dwarf mass, eventually causing carbon/oxygen burning and finally explosion.**

# Leading Model of (most) Type Ia Supernova:

- **Explosion: $2\,{}^{12}C + 2\,{}^{16}O \rightarrow {}^{56}Ni$ (0.3 to 1.1 solar masses) ${}^{56}Ni \rightarrow {}^{56}Co \rightarrow {}^{56}Fe$ gamma rays fuel LC**

- **Why does stretch work? (Why is brighter = broader?)**
  - **Hotter explosion makes more ${}^{56}Ni$**
  - **Hotter explosion causes more opacity due to ionization, until expanding sphere cools off over 1-2 weeks.**

# Leading Model of (most) Type Ia Supernova:

- **Heavier elements can change things:**
  **$2\ {}^{12}C + 3\ {}^{16}O + 2\ {}^{22}Ne \rightarrow 2\ {}^{58}Ni$**
  **(reducing ${}^{56}Ni$) (stretch overcorrection)**

- **Heavier elements come from previous ~billion years of supernovae and novae.**

- **Older galaxies should have white dwarfs with heavier elements. But depends on star formation history, very complicated.**

# Host Galaxy Elements Heavier than Helium (metallicity)

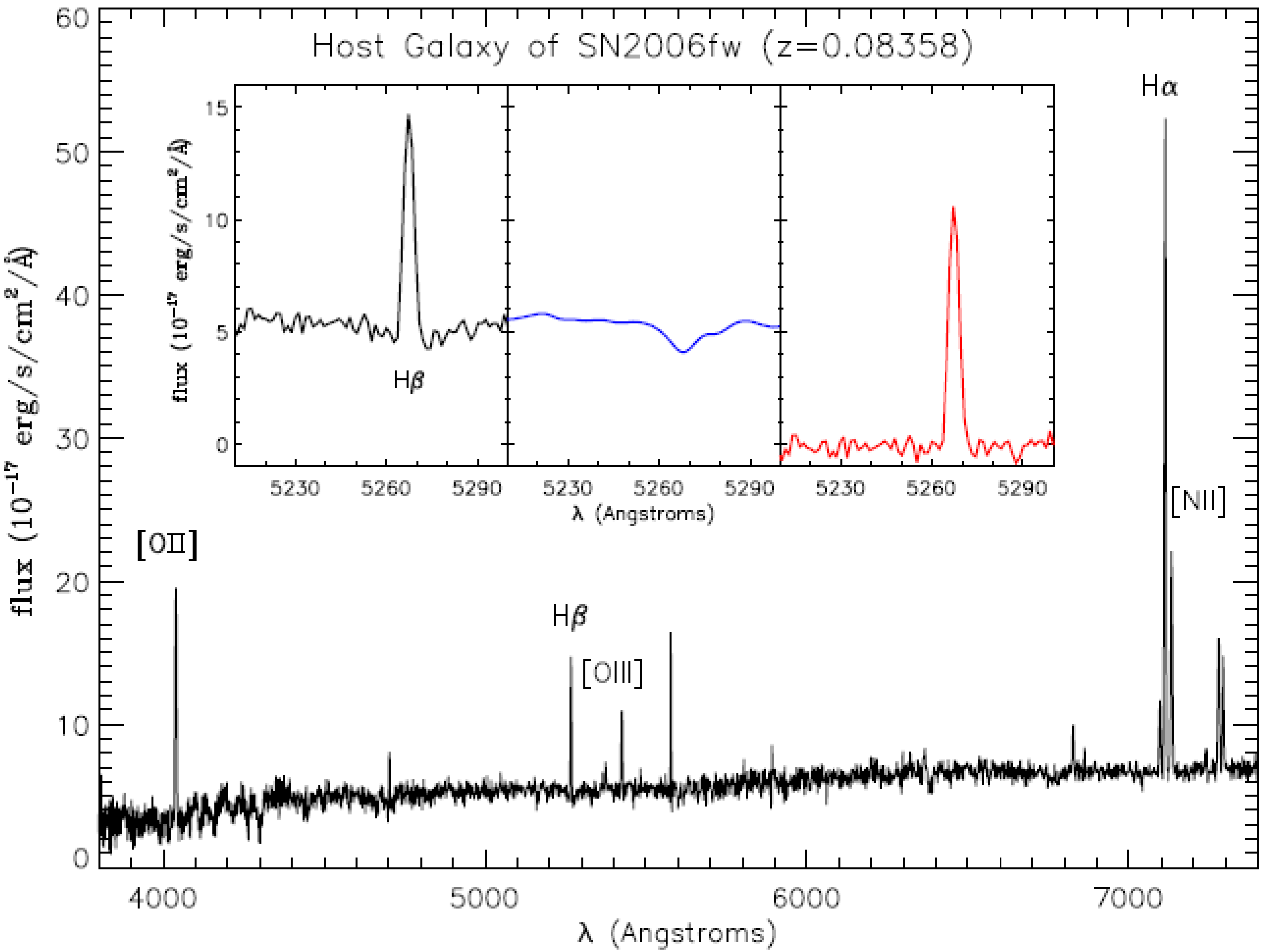
- **Measure color, luminosity, shape, and maybe spectrum of galaxy.**

- **Infer mass, age, metallicity, and star formation rate (and all correlated).**

- **That’s just for the galaxy, then have to infer the effect on the SNIa white dwarf.**

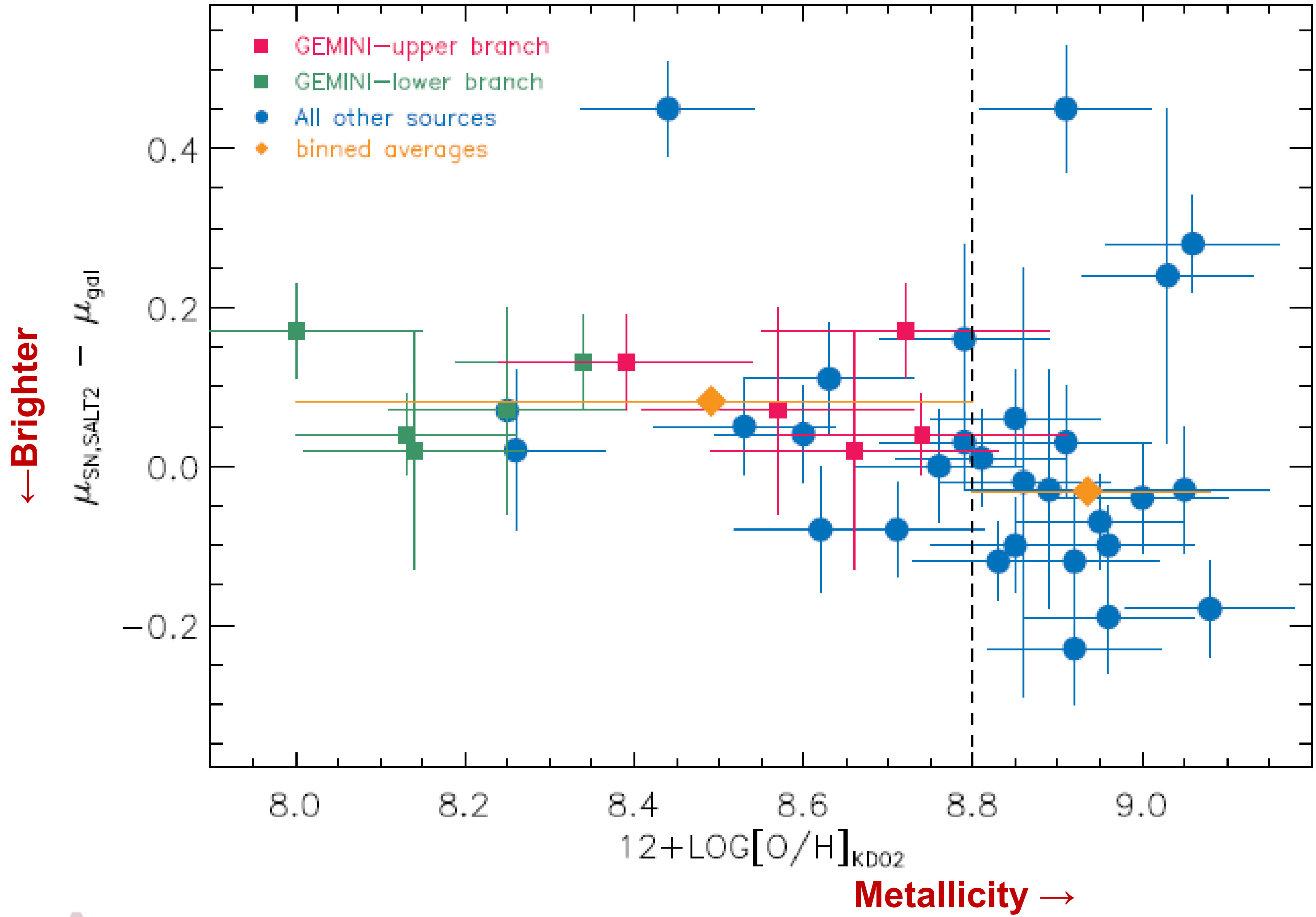
# Spectroscopic Properties of Star-Forming Host Galaxies and Type Ia Supernova Hubble Residuals in a Nearly Unbiased Sample

Chris B. D'Andrea[1,2], Ravi R. Gupta[1], Masao Sako[1], Matt Morris[1,3], Robert C. Nichol[2], Peter J. Brown[4], Heather Campbell[2], Matthew D. Olmstead[4], Joshua A. Frieman[5,6,7], Peter Garnavich[8], Saurabh W. Jha[9], Richard Kessler[5,6], Hubert Lampeitl[2], John Marriner[7], Donald P. Schneider[10], Mathew Smith[11]



Host Galaxy of SN2006fw (z=0.08358)
flux ($10^{-17}$ erg/s/cm$^2$/Å)
λ (Angstroms)
[OII]
Hβ
[OIII]
Hα
[NII]

## Standard light curve fit overcorrecting the SNIa brightness at large metallicity



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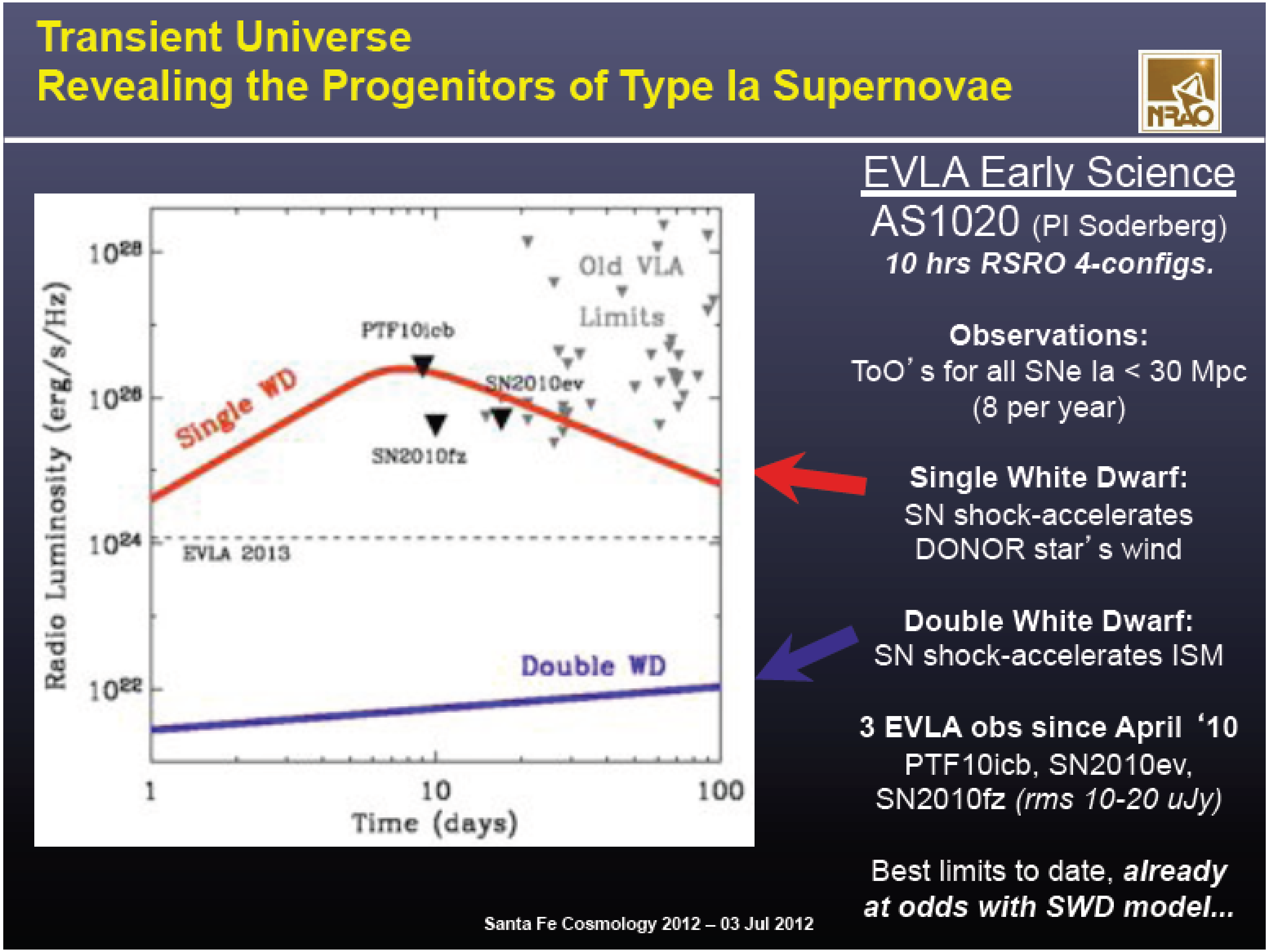
# Type Ia Progenitors

- Two competing models:
    - Single white dwarf + accretion from "normal" companion (SD)
    - Double white dwarf + gravitational wave losses cause merger (DD)

- Main observational constraints (out of about a dozen)
    - SD should see early radio, x-ray, UV (none seen, big problem)
    - SD should see occasionally the surviving companion, none conclusively seen
    - Couple of SNe have evidence of circumstellar material in spectra, supporting SD for those.
    - Delay Time Distribution supports at least a good fraction of DD

- Overall DD model is rising in popularity, have to explain homogeneity of SNIa brightness and fluctuations.

# Steve Myer's slide on radio limits of SD



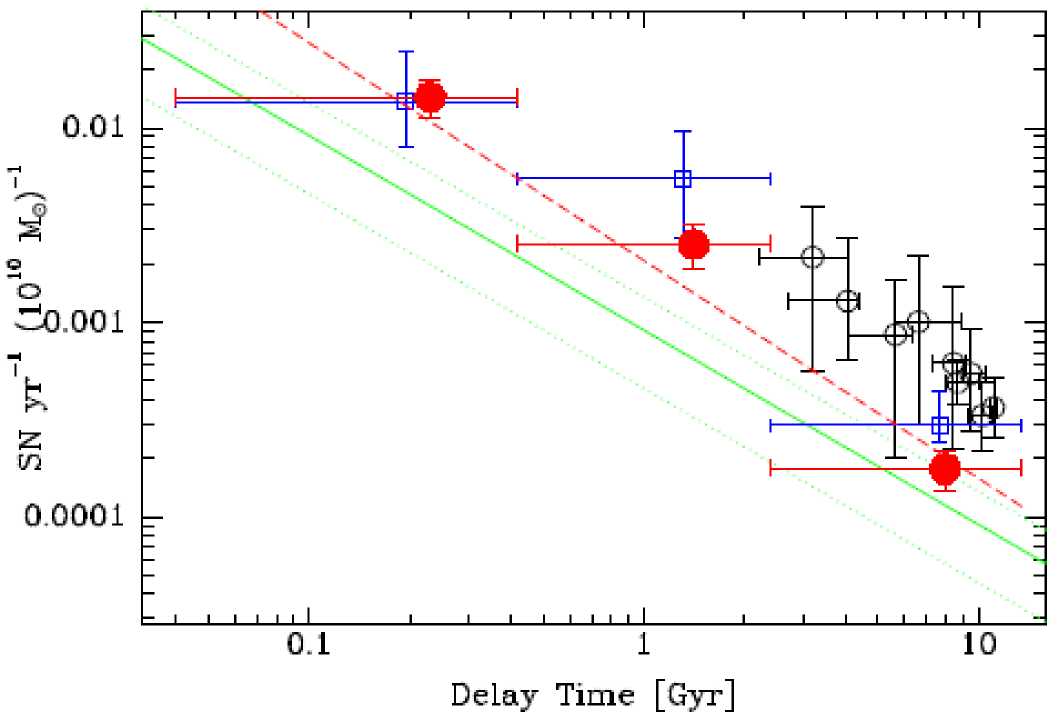
## Delay Time Distibutions (time from galaxy star formation burst to SNIa)

- SD model:
  - Expected less than 3 Gyr, most models less than 1 Gyr
  - Limited range of accretion rates
    - Too fast causes common envelope and no explosion
    - Too slow and goes nova instead of supernova

- DD model:
  - Time to make two white dwarfs + time for gravitational wave losses
  - Time to make merger goes like binary separation $a^4$
  - If separations distributed like 1/a, expect $t^{-1}$

# The Delay Time Distribution of Type-Ia Supernovae from Sloan II

Dan Maoz[1★], Filippo Mannucci[2], Timothy D. Brandt[3]
[1] School of Physics and Astronomy, Tel-Aviv University, Tel-Aviv 69978, Israel
[2] INAF - Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi 5, Firenze 50125, Italy
[3] Department of Astrophysical Sciences, Ivy Lane, Princeton University, Princeton, NJ 08540, USA




**Red line is best fit ($t^{-1.12}$)   Less evidence for two components.**
**Many observations at times too long for SD**

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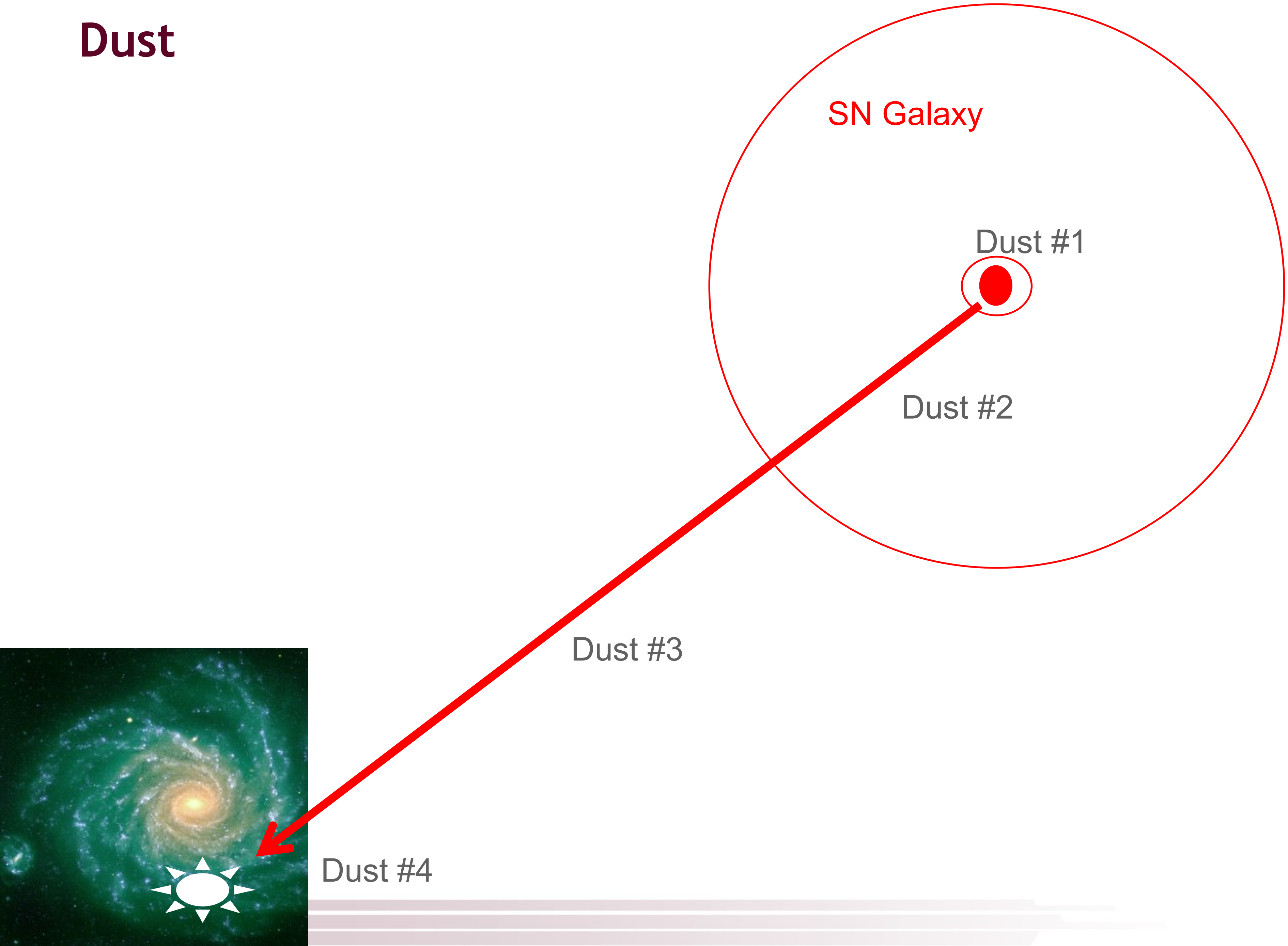
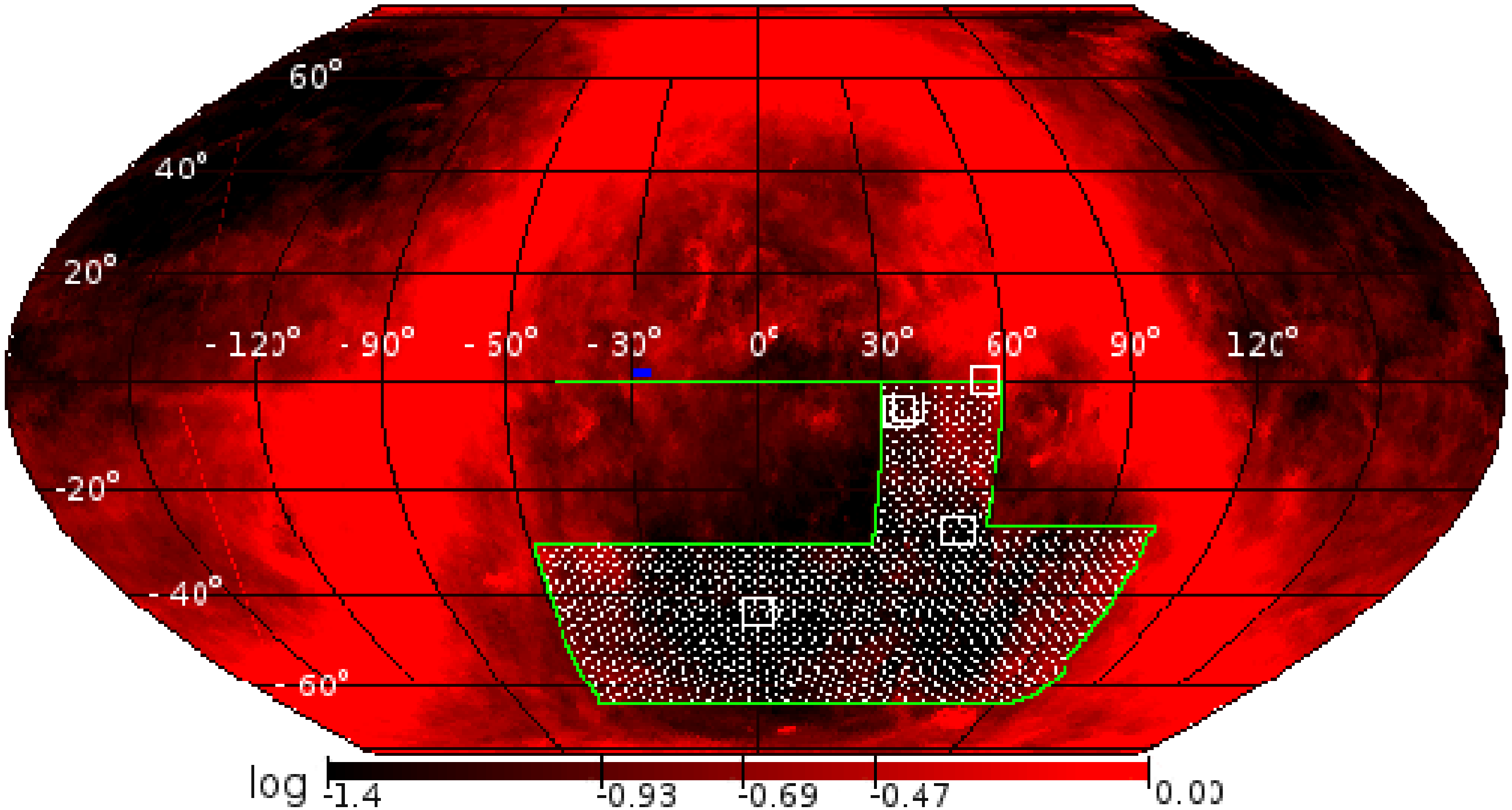
**Dust/color**

# Dust



#4: Milky Way dust.  This is Schlegel map of DES area and 5 SN fields.

Darker is LESS dust.   Pretty well understood and most groups point away from dust.

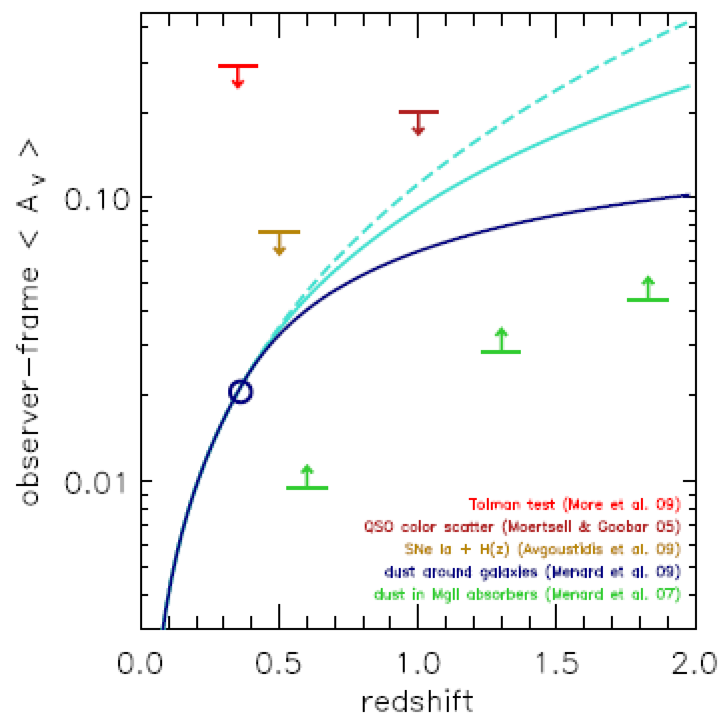


## #3: Intergalactic dust. Not a large effect but cannot ignore.

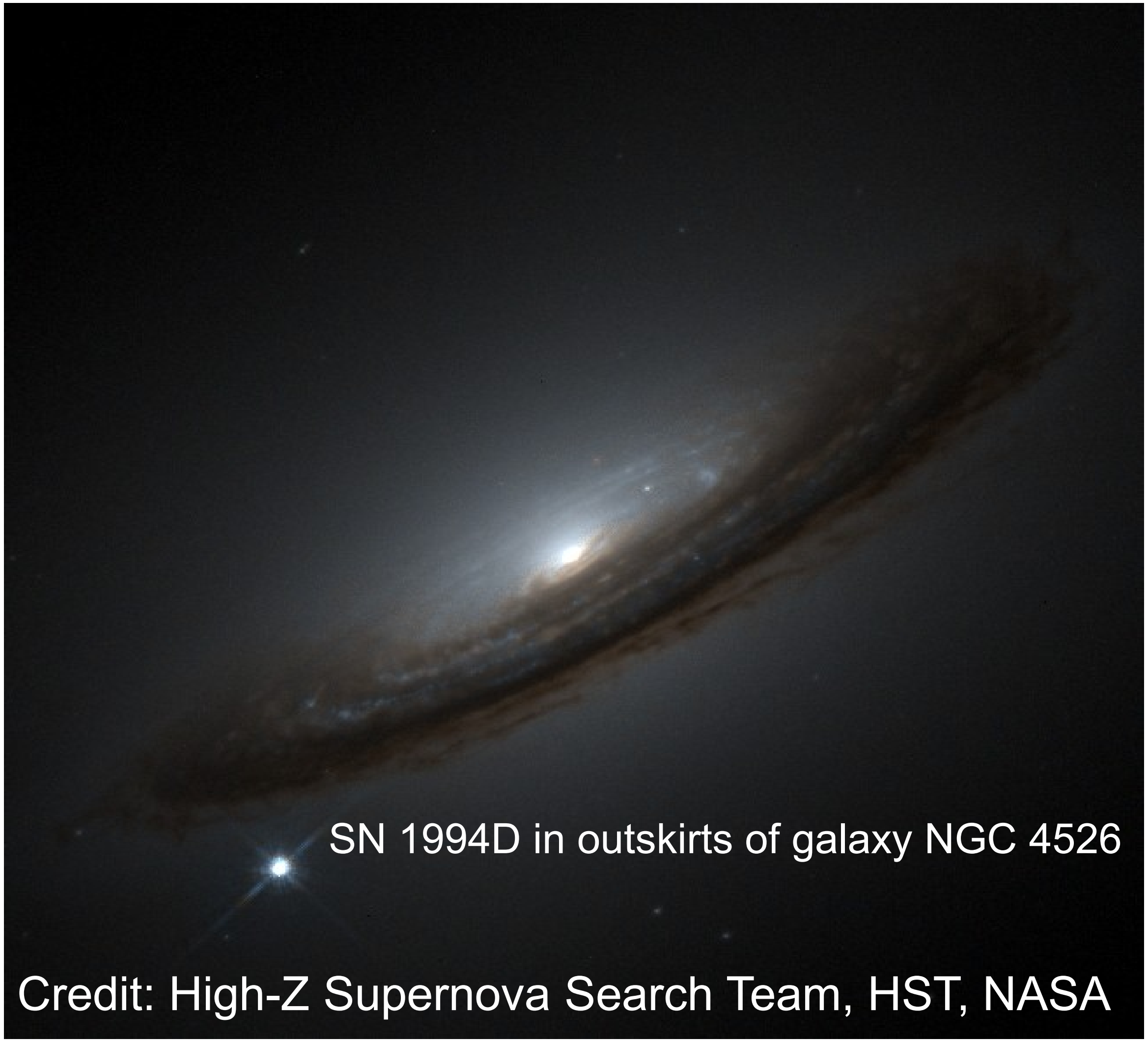
**Measuring the galaxy-mass and galaxy-dust correlations through magnification and reddening**

Brice Ménard[1], Ryan Scranton[2], Masataka Fukugita[3,4], Gordon Richards[5]

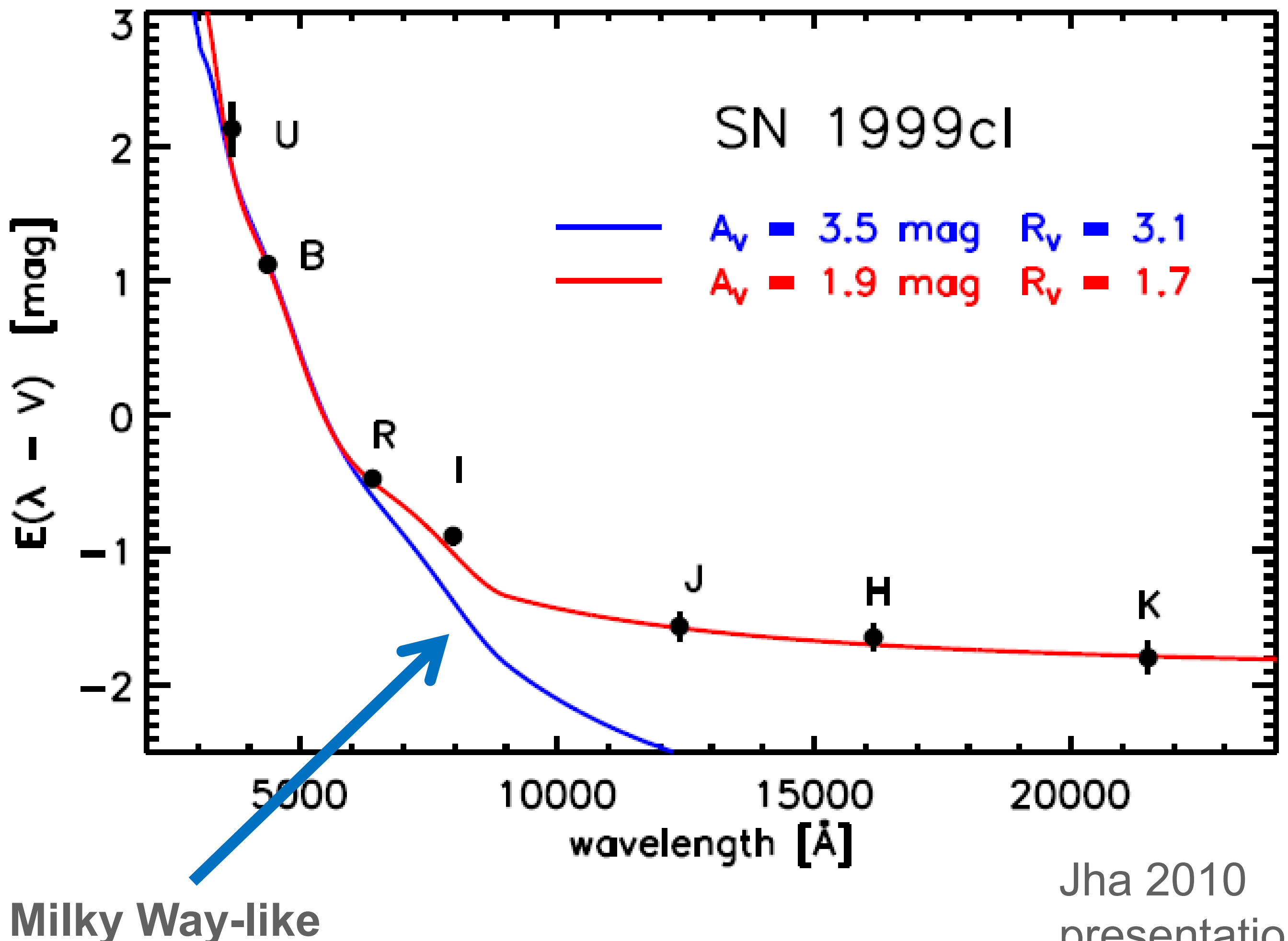
[1] *Canadian Institute for Theoretical Astrophysics*
[2] *University of California-Davis*
[3] *Institute for Advanced Study*
[4] *Tokyo University*
[5] *Drexel University*



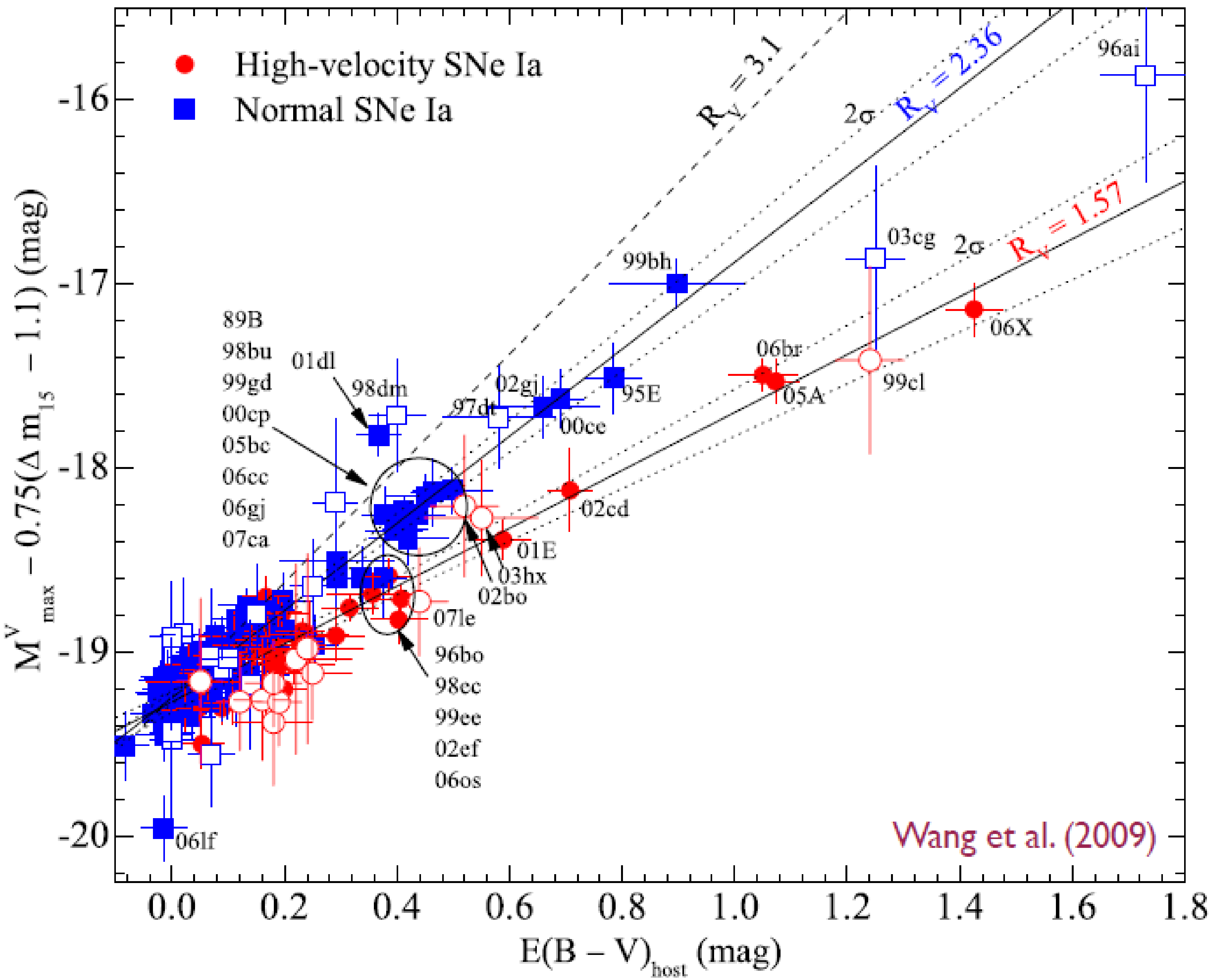
#2 and #1: SN galaxy dust and dust from region around SN, is it the same as the Milky Way or not?



RV = AV/E(B-V)
Typical SNe values below Milky Way




Jha 2010 presentation

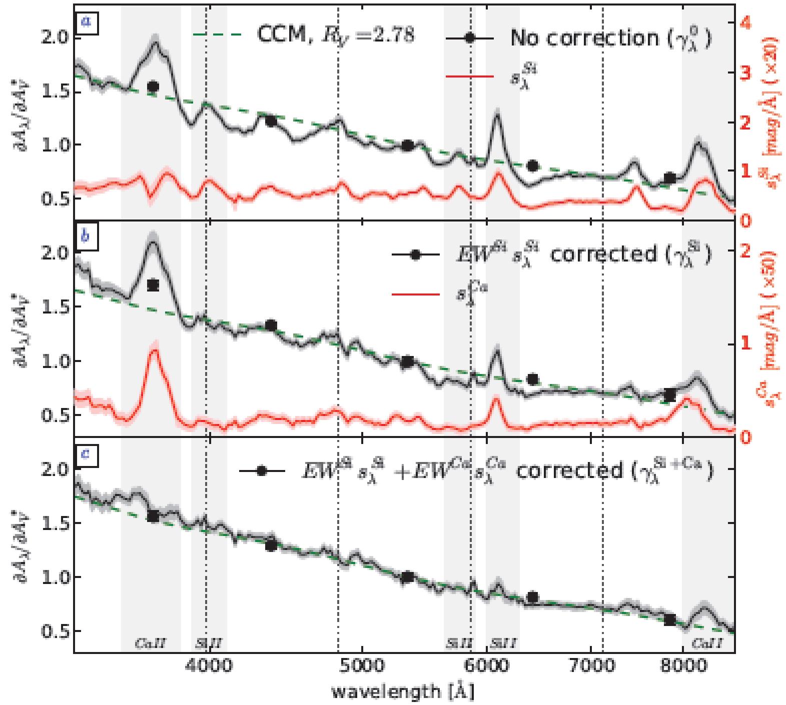


High-velocity SNe Ia
Normal SNe Ia
$R_V = 3.1$
$R_V = 2.36$
$R_V = 1.57$
2σ
2σ
96ai
99bh
03cg
06X
06br
05A
99cl
02cd
01E
03hx
02bo
07le
95E
02gj
00ce
97dt
98dm
01dl
89B
98bu
99gd
00cp
05bc
06cc
06gj
07ca
96bo
98ec
99ee
02ef
06os
06lf
Wang et al. (2009)
$M^V_{max} - 0.75(\Delta m_{15} - 1.1)$ (mag)
$E(B-V)_{host}$ (mag)
-16
-17
-18
-19
-20
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8

# The reddening law of Type Ia Supernovae: separating intrinsic variability from dust using equivalent widths

The Nearby Supernova Factory:
N. Chotard[1], E. Gangler[1], G. Aldering[2], P. Antilogus[3], C. Aragon[2], S. Bailey[2], C. Baltay[4], S. Bongard[3], C. Buton[5], A. Canto[3], M. Childress[2,6], Y. Copin[1], H. K. Fakhouri[2,6], E. Y. Hsiao[2], M. Kerschhaggl[5], M. Kowalski[5], S. Loken[2], P. Nugent[7,8], K. Paech[5], R. Pain[3], E. Pecontal[9], R. Pereira[1], S. Perlmutter[2,6], D. Rabinowitz[4], K. Runge[2], R. Scalzo[4,10], G. Smadja[1], C. Tao[11,12], R. C. Thomas[7], B. A. Weaver[13], and C. Wu[3,14]

1) Consensus that treatment of color fluctuations and their correlations can move RV closer to Milky Way (this 2011 SNF paper reviews that)
2) SNF also points out that silicon and calcium peaks in spectrum can help mimic a low RV
3) New paper on color fluctuations from Kessler and the SALT retraining group on the way…



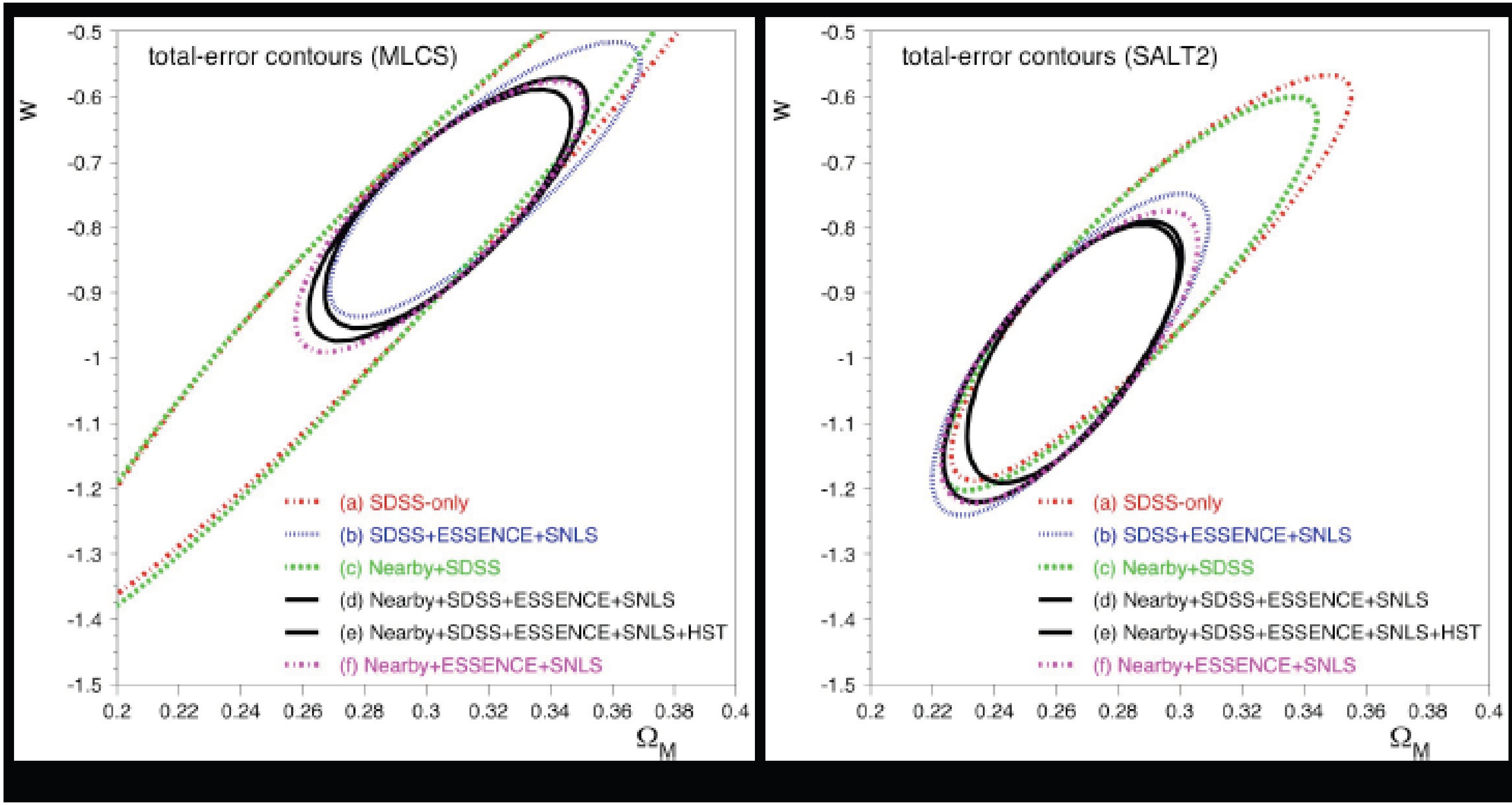
- Type Ia SNe Light Curves
- SALT2  Light Curve Model Basics
- Union 2.1 Sample (SCP)  plots not in their paper or their web page
- Cosmology Fit Results vs Priors   (and systematics)
- Calibration
- Type Ia brightness correlations with host galaxy properties
- Type Ia Progenitor Systems
- Dust/Color
- UV problem
- Evolution with redshift/Main Conclusions
- Dark Energy Survey  SNe Cosmology optimization
- Core Collapse SNe contamination of photometric samples

# Union 2.1 SN systematics

| Source | Error on Constant $w$ |
|---|---|
| Vega | 0.033 |
| All Instrument Calibration | 0.030 |
| (ACS Zeropoints) | 0.003 |
| (ACS Filter Shift) | 0.007 |
| (NICMOS Zeropoints) | 0.007 |
| Malmquist Bias | 0.020 |
| Color Correction | 0.020 |
| Mass Correction | 0.016 |
| Contamination | 0.016 |
| Intergalactic Extinction | 0.013 |
| Galactic Extinction Normalization | 0.010 |
| Rest-Frame $U$-Band Calibration | 0.009 |
| Lightcurve Shape | 0.006 |
| *Quadrature Sum of Errors/ Sum of Area (not used)* | *0.061* |
| Summed in Covariance Matrix | 0.048 |

**UV problem**

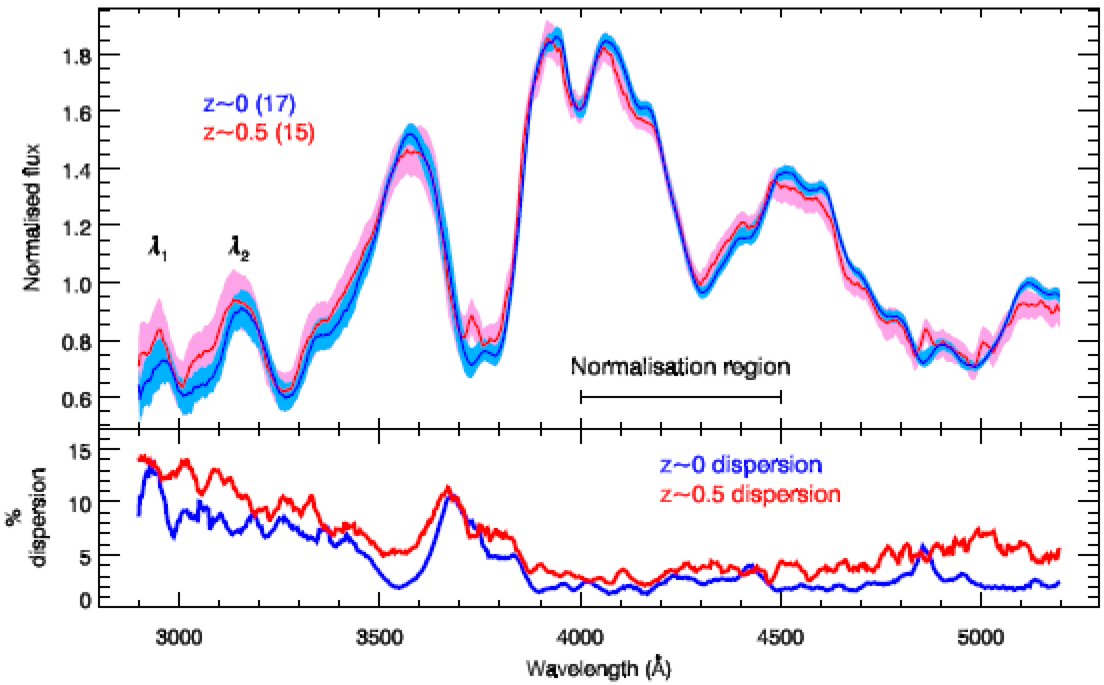
# UV problem (Kessler 2009)



# UV problem

***Hubble Space Telescope* studies of low-redshift Type Ia supernovae: Evolution with redshift and ultraviolet spectral trends**

K. Maguire,[1*] M. Sullivan,[1] R. S. Ellis,[2] P. E. Nugent,[3,4] D. A. Howell,[5,6] A. Gal-Yam,[7] J. Cooke,[8], P. Mazzali,[9,10] Y-C. Pan,[1] B. Dilday,[5,6] R. C. Thomas,[3,4] I. Arcavi,[7] S. Ben-Ami,[7] D. Bersier,[11] F. B. Bianco,[5,6] B. J. Fulton,[5] I. Hook,[1,12] A. Horesh,[2] E. Hsiao,[13] P. A. James,[11] P. Podsiadlowski,[1] E. S. Walker,[14] O. Yaron,[7] M. M. Kasliwal,[15] R. R. Laher,[16] N. M. Law,[17] E. O. Ofek,[7] D. Poznanski,[18] J. Surace[2]



- Type Ia SNe Light Curves
- SALT2 Light Curve Model Basics
- Union 2.1 Sample (SCP) plots not in their paper or their web page
- Cosmology Fit Results vs Priors (and systematics)
- Calibration
- Type Ia brightness correlations with host galaxy properties
- Type Ia Progenitor Systems
- Dust/Color
- UV problem
- Evolution with redshift BIG QUESTION: WHICH EFFECTS ARE CHANGING WITH REDSHIFT IN WAYS WE DON'T KNOW
- Dark Energy Survey SNe Cosmology optimization
- Core Collapse SNe contamination of photometric samples

# DES SN Survey Basics and Simulation Studies

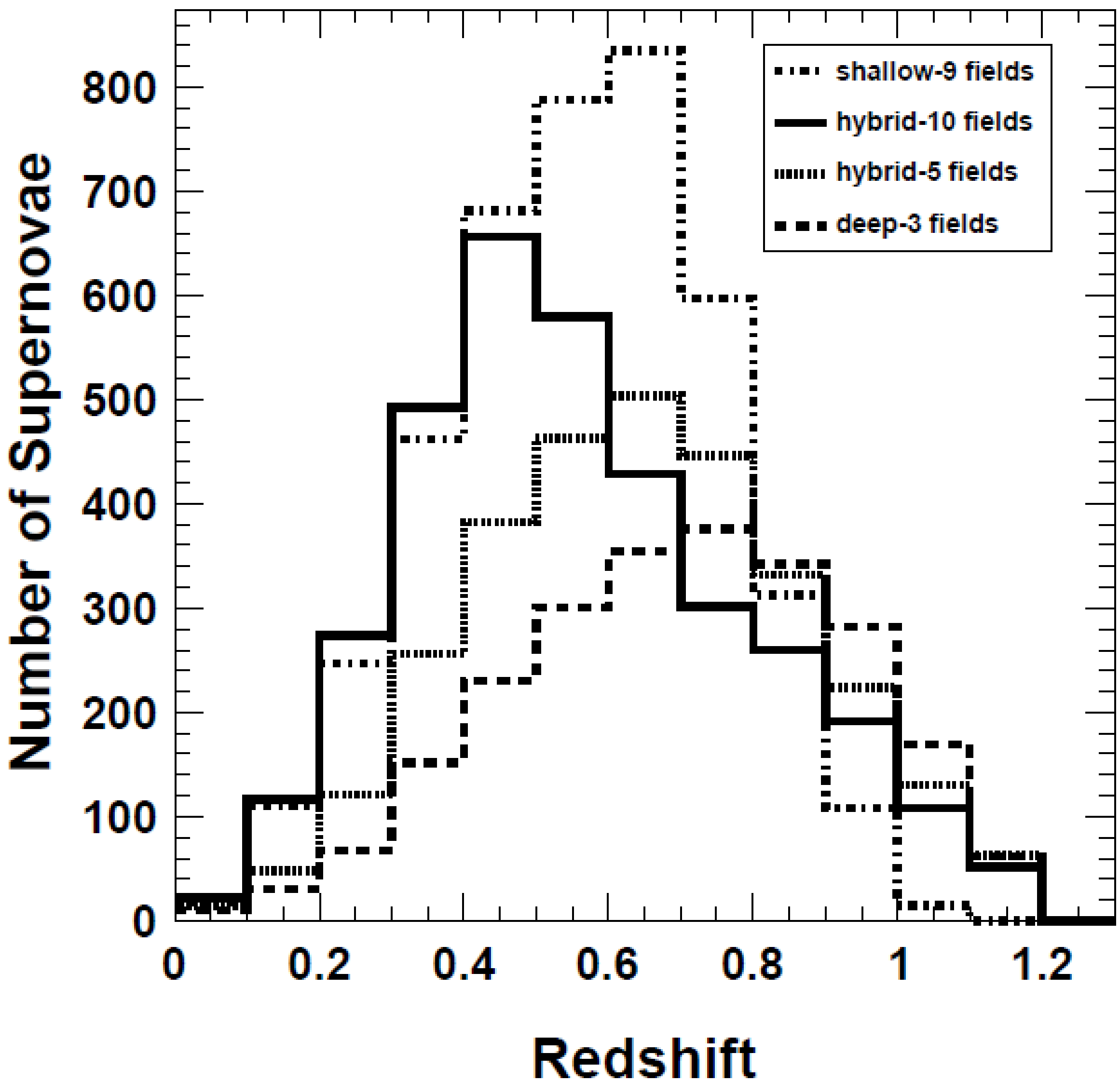
Steve Kuhlmann (Most simulations by Joe Bernstein)

Argonne National Laboratory

2011-10-12

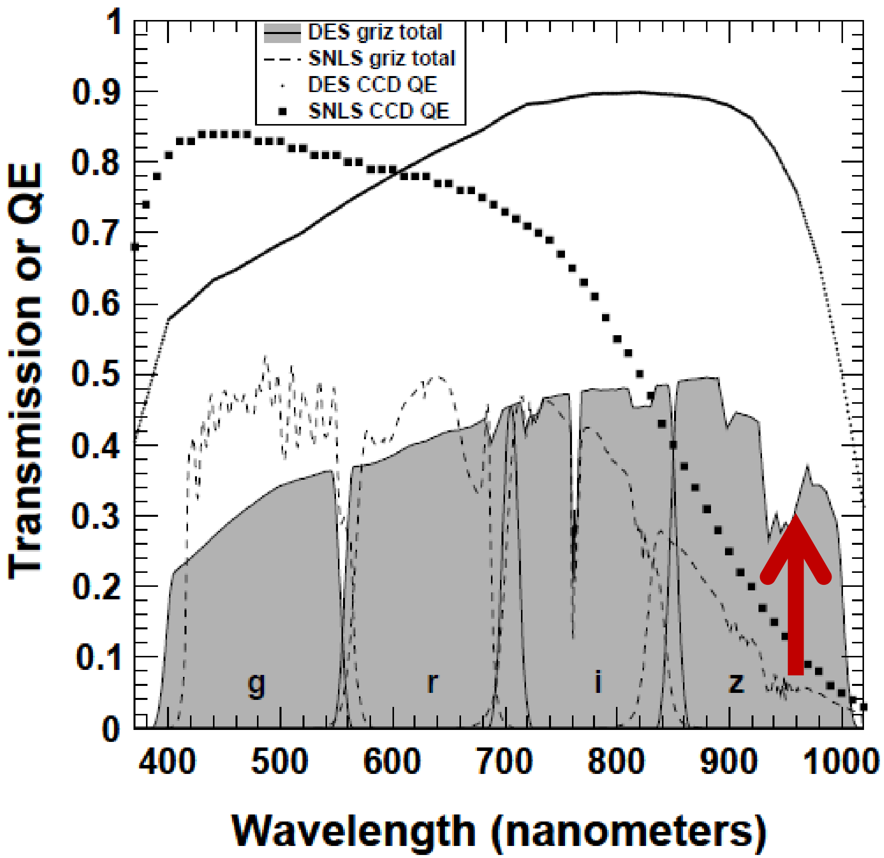
- **Current Favorite Survey: 2 "Deep" and 8 "Shallow" fields, 30 sq. deg total.**
- **Hybrid mixture keeps 70% of high-z SN and adds >1000 mid-z SN.**
- **10-field hybrid also best DE constraint (not a strong dependence on choice).**
- **Five favorite fields in table (three fields overlap with VIDEO IR)**
- **Other five fields still under discussion.**

| Field ($3\ \mathrm{deg}^2$ area) | Pointing RA&Dec (deg., J2000) |
|---|---|
| *Chandra* Deep Field S. | 52.5°, –27.5° |
| XMM-LSS | 34.5°, –5.5° |
| Sloan Stripe 82 | 55.0°, 0.0° |
| SNLS D1/Virmos VLT | 36.75°, –4.5° |
| ELAIS S1 | 0.5°, –43.0° |


shallow-9 fields
hybrid-10 fields
hybrid-5 fields
deep-3 fields
Number of Supernovae
0
100
200
300
400
500
600
700
800
0
0.2
0.4
0.6
0.8
1
1.2
Redshift

# Exposure times and limiting magnitudes

- **Focus on red bands due to improved CCD red sensitivity.**
- **Expect total exposure time ~1200 hours over 5 years.**
- **Exposures tuned for equal r,i,z SNR at z=1 in deep fields, and equal g,r,i,z SNR at shallow field redshift peak. (~1 hour/visit in z-band deep fields!)**




| Filter | Deep Fields | Shallow Fields |
|---|---|---|
| $g$ | 27.1 | 26.8 |
| $r$ | 27.3 | 25.6 |
| $i$ | 27.0 | 25.9 |
| $z$ | 26.8 | 25.7 |

Table 5:: Limiting magnitudes for point sources detected at $5\sigma$ in the DES 10-field hybrid survey, using a 1-season co-add.

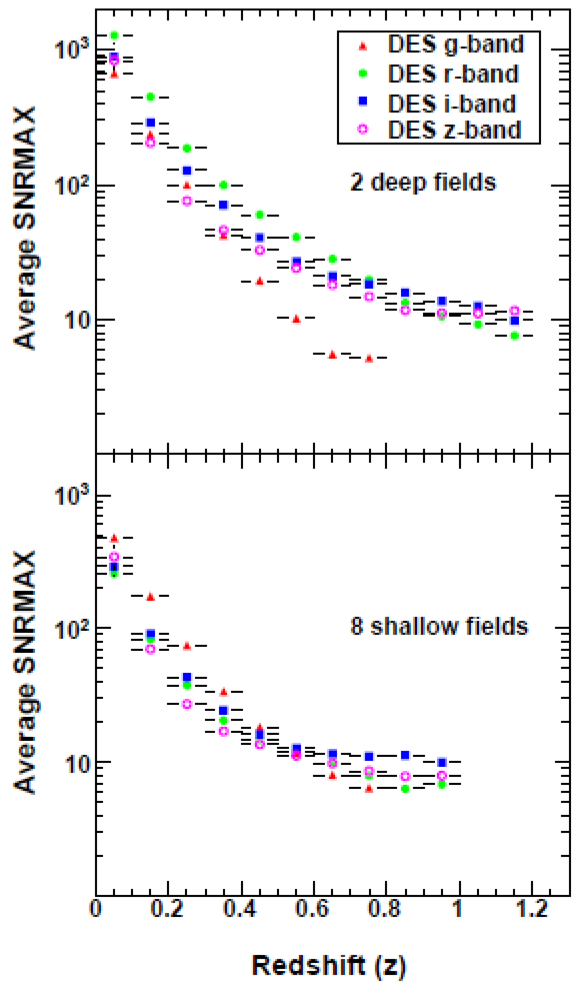
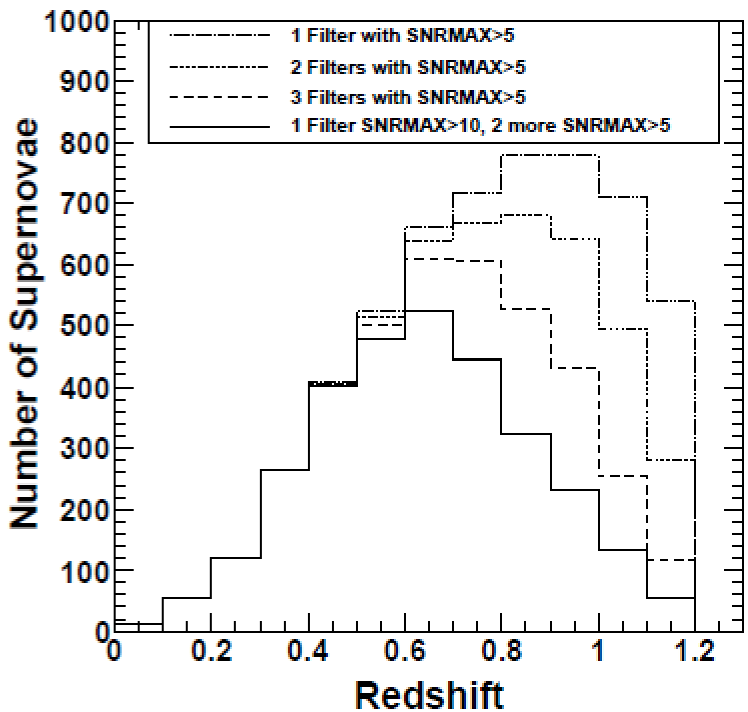
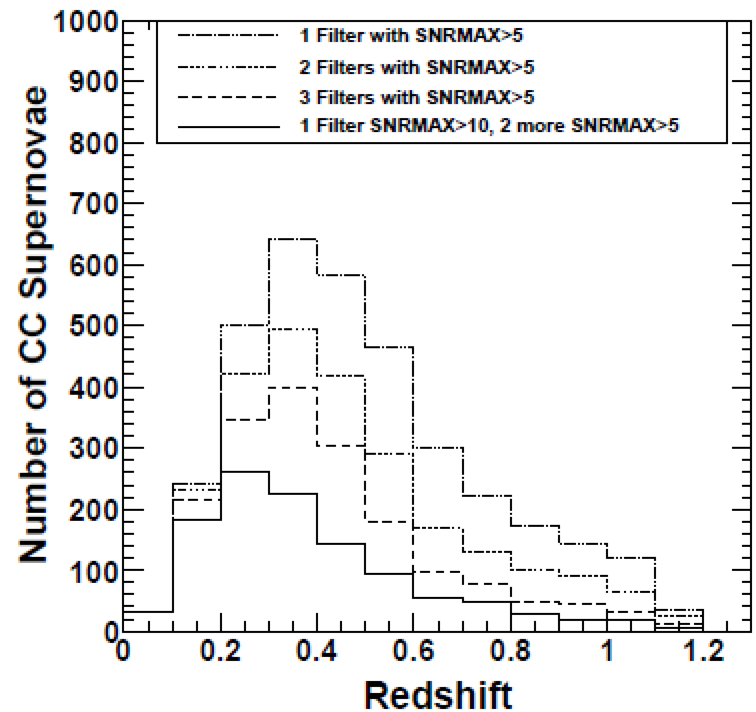



Fig. 7.—: Average signal-to-noise at maximum brightness (SNRMAX) for the 10-field hybrid strategy as a function of redshift for the DES $g$-, $r$-, $i$-, and $z$-bands.

# Simulations and SNR cuts

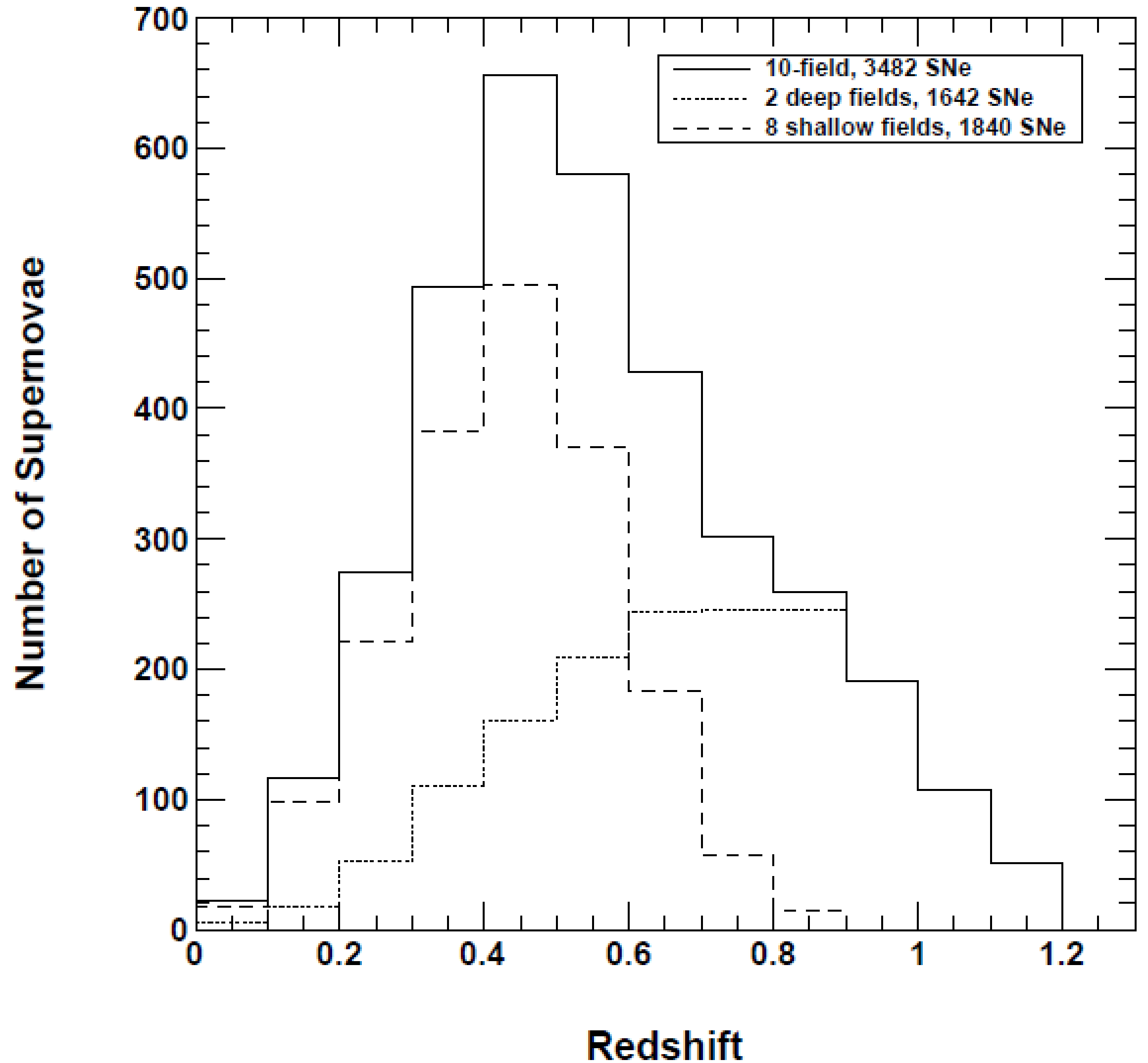
- Simulations use SNANA, simulating 5 year survey.
- SNIa simulated with MLCS2k2 and SALT2 models. Core collapse simulated using 40 templates from Photometric Challenge.
- Default SNR cuts for our upcoming simulation paper is meant to optimize purity, requiring 1 filter with maximum SNR>10, plus 2 more filters with SNR>5. (more on purity later…)



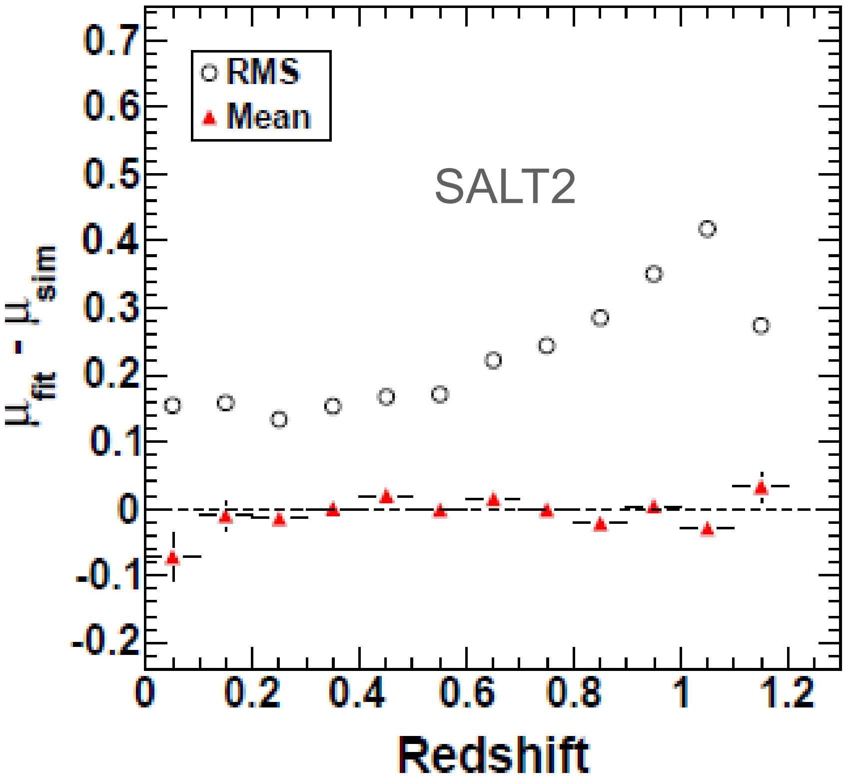



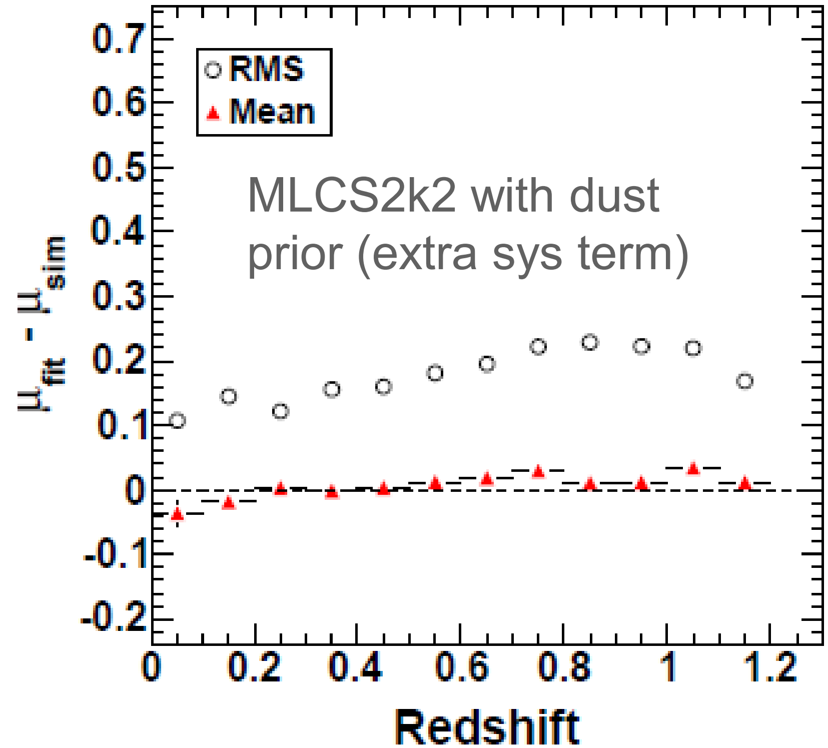
# Redshift distributions

- SNIa redshift distributions from deep and shallow fields using cuts on previous slide.



# DES SN Survey Basics and Simulation Studies



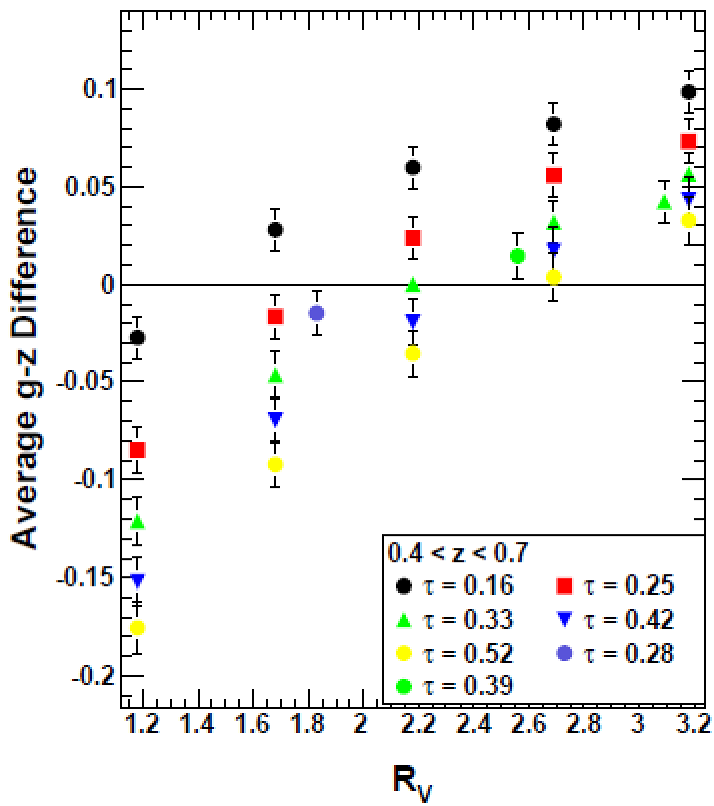
# Redshift Determination

- **Assume host redshifts obtained for majority of SNIa.**
- **SNIa spectral follow-up provides samples for systematic studies. (A. Kim talk)**
- **Cosmology projections degraded based on lack of host redshift.**

| Redshift | SNLS Data | Model |
|---|---|---|
| 0.1-0.2 | 100% | 98% |
| 0.2-0.3 | 94.4% | 97% |
| 0.3-0.4 | 97.4% | 94% |
| 0.4-0.5 | 96.5% | 92% |
| 0.5-0.6 | 94.1% | 89% |
| 0.6-0.7 | 79.0% | 85% |
| 0.7-0.8 | 88.6% | 82% |
| 0.8-0.9 | 78.4% | 78% |
| 0.9-1.0 | 76.9% | 74% |
| 1.0-1.1 | 50.0% | 70% |
| 1.1-1.2 | N/A | 67% |

Table 7:: Measured (SNLS, Hardin et. al, in preparation) and estimated percentages of SNIa host galaxies with $m_i < 24$ are tabulated. The model values are taken from the middle column of table 18 from Appendix B. For both the data and model, the uncertainties grow from a few % at low redshift to ±25% for z>1.0.

# Simple Color studies so far



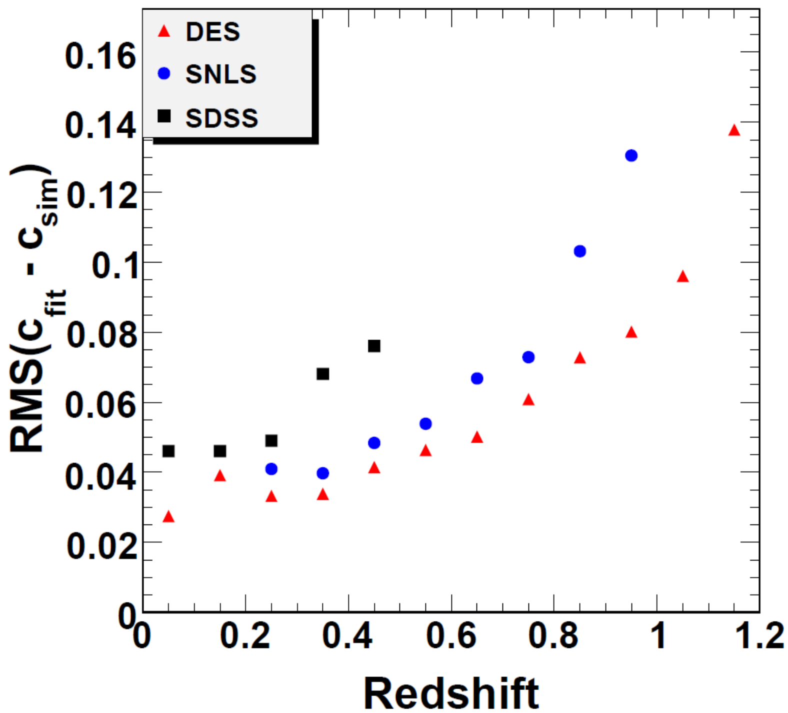



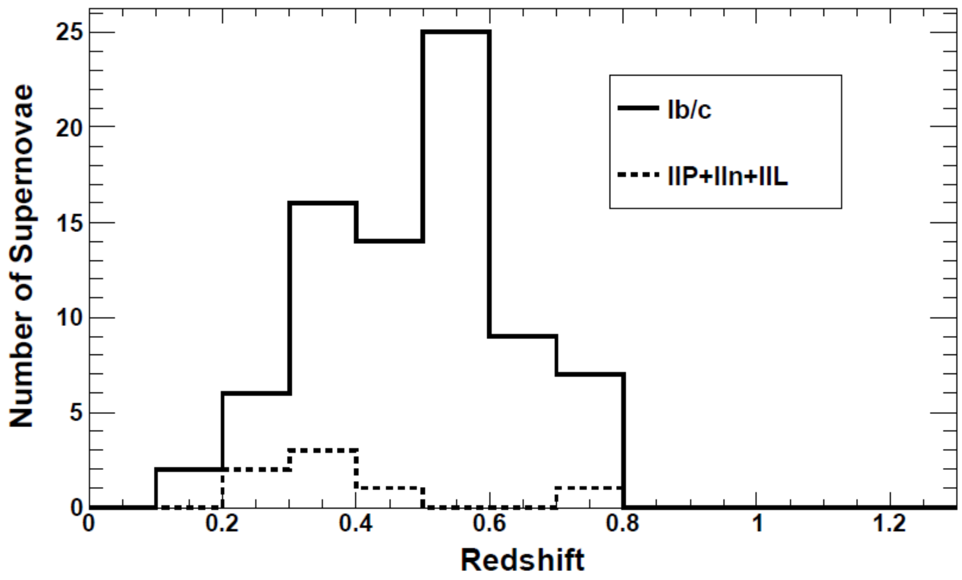

Fig. 20.—: Average $g-z$ color difference assuming the 5-field hybrid strategy for epoch<11 compared to the reference simulation with ($R_V$ = 2.18, $\tau_{A_V}$ = 0.334) as a function of $R_V$ and for a range of $\tau_{A_V}$.

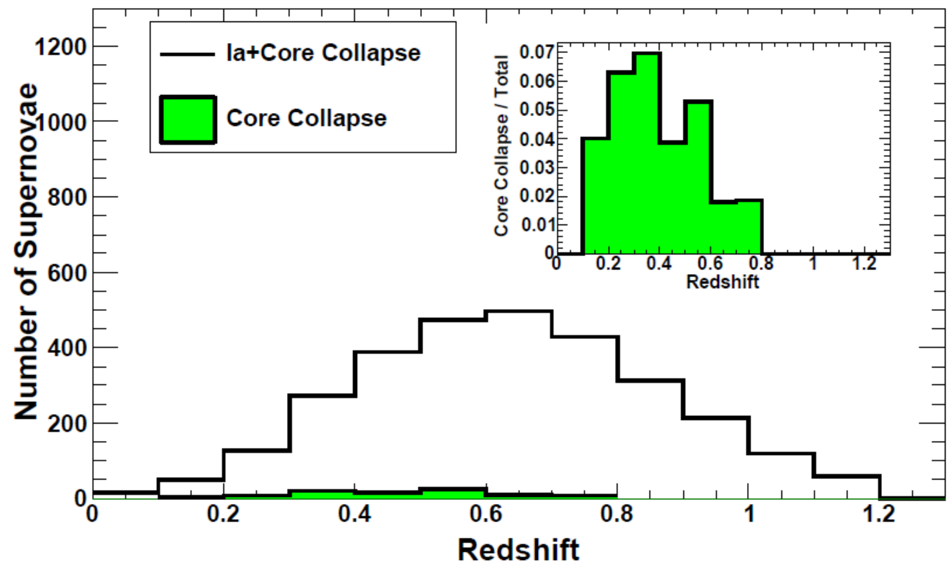
# Purities

- Table shows purities with and without MLCS fit probability cut.
- We expect to improve completeness by relaxing SNR cuts and using more sophisticated typers.

| Sample | $f_p > 0.0$ | $f_p > 0.1$ |
|---|---|---|
| Ib/c | 509 | 79 |
| IIP | 196 | 6 |
| IIn | 94 | 1 |
| IIL | 68 | 0 |
| Total SNcc | 867 | 86 |
| Ia | 2984 | 2872 |
| Ia+SNcc | 3851 | 2958 |
| Sample Ia Purity | 77% | 97.1% |

| Simulation Input | Total SNcc |
|---|---|
| Defaults | 86 |
| Nugent templates | 145 |
| Sako et al. templates | 133 |
| Li et al. Ib/c abs. magnitude | 46 |



# DES SN Survey Basics and Simulation Studies

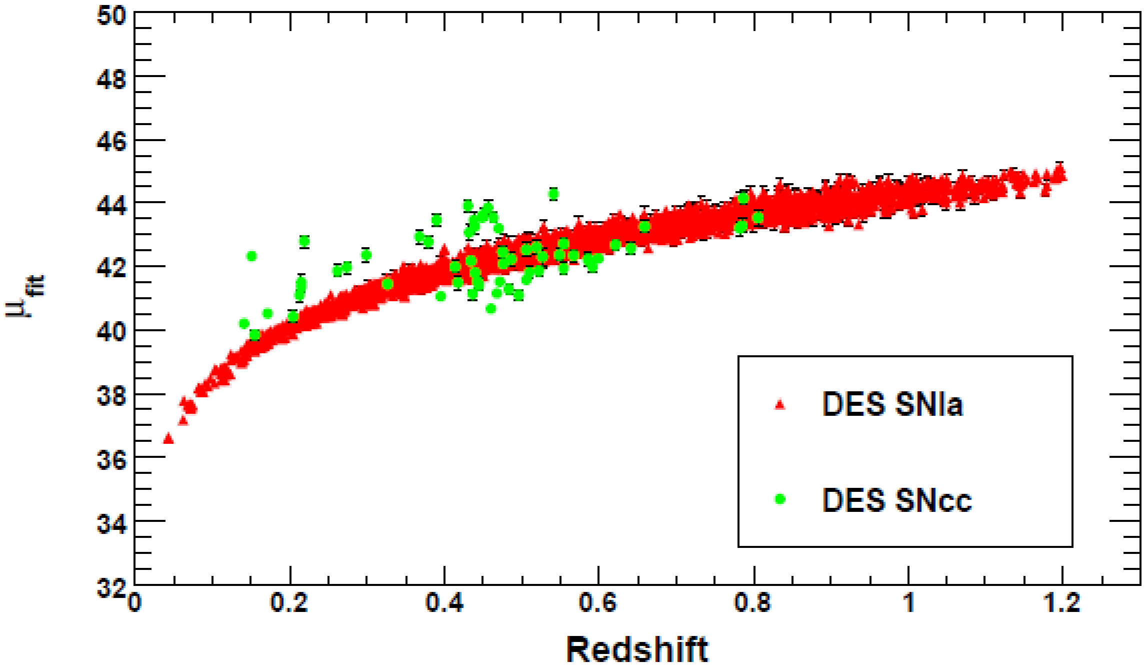
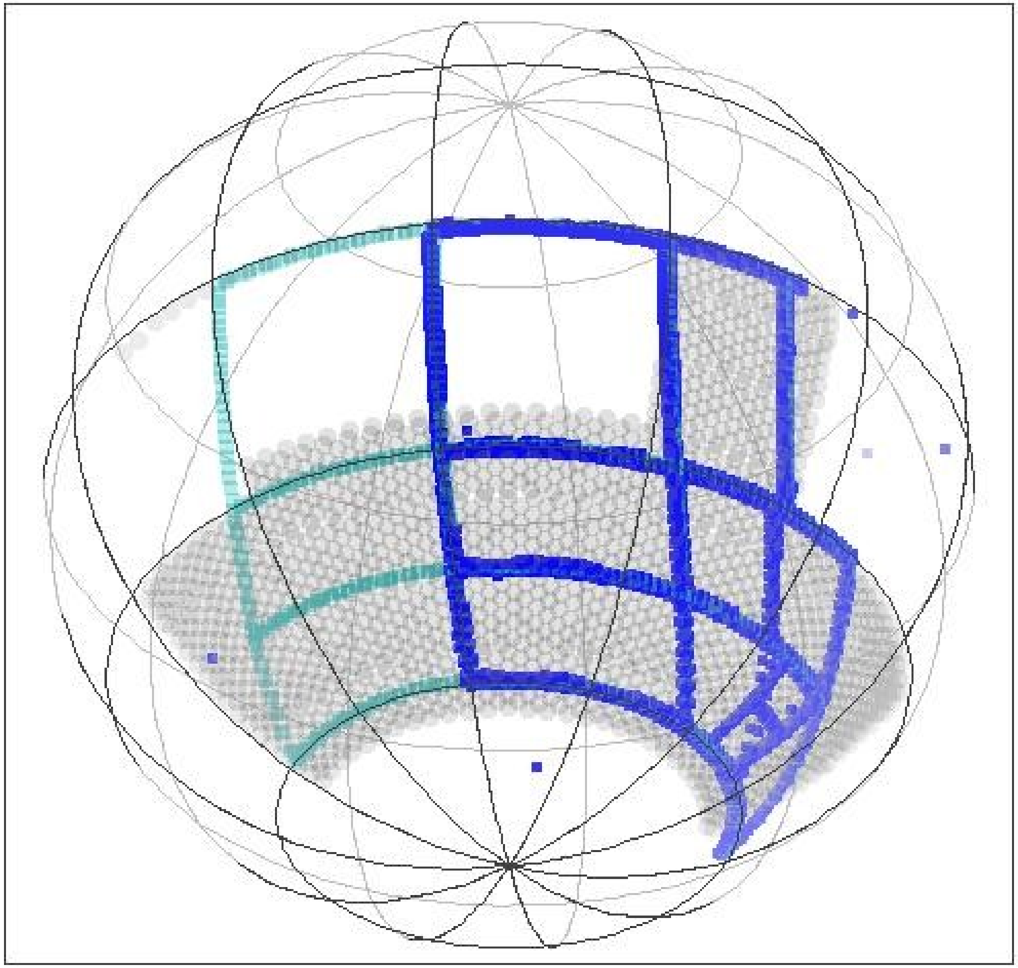



Fig. 24.—: Hubble diagram of individual SNIa and SNcc for the hybrid 10-field survey.

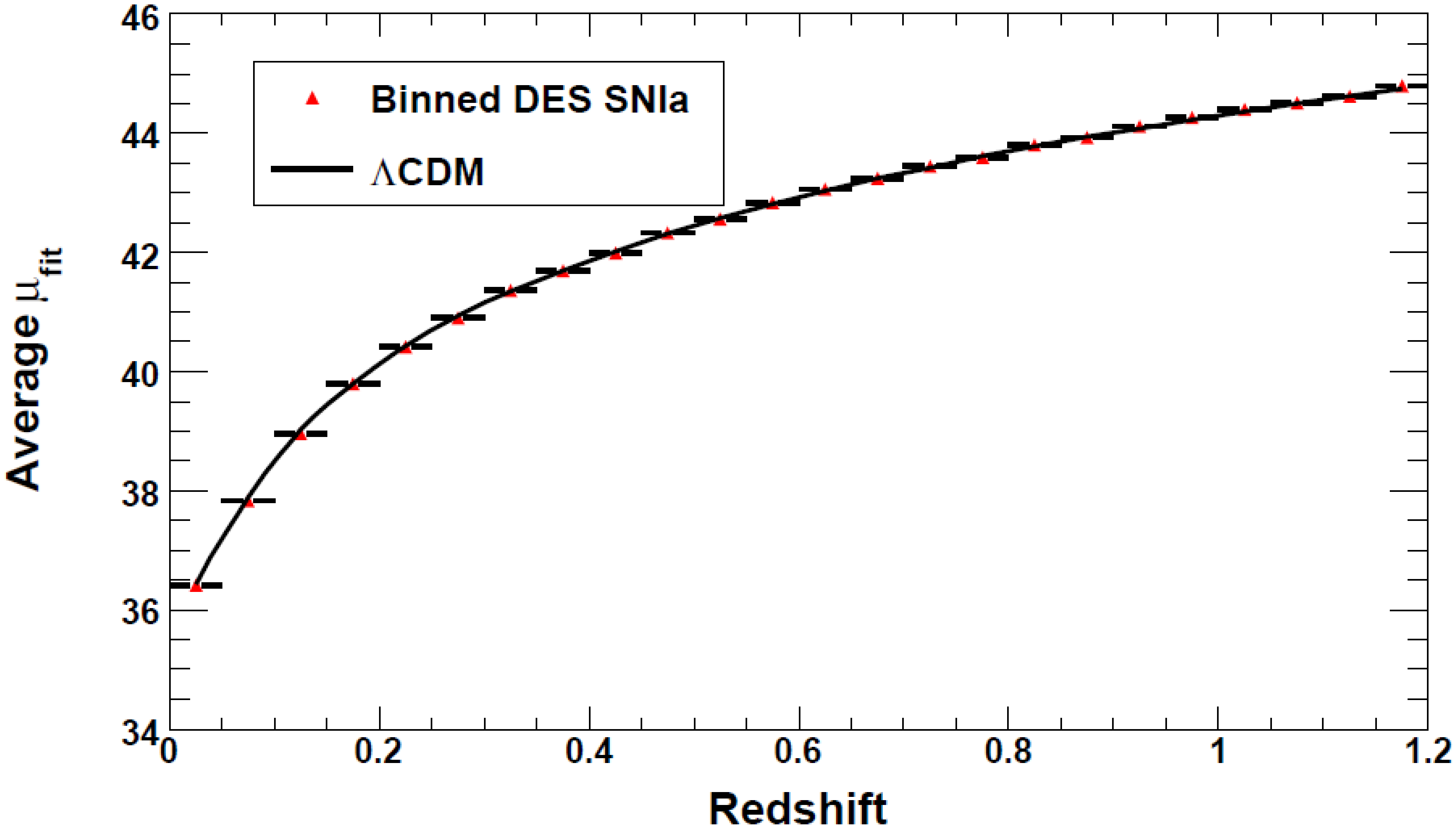
**Only significant shift in average mu if binned with SNIa is at z=0.22, and neighboring bins have no mu shift.**

# Emphasis on calibrations and intercalibration with SDSS

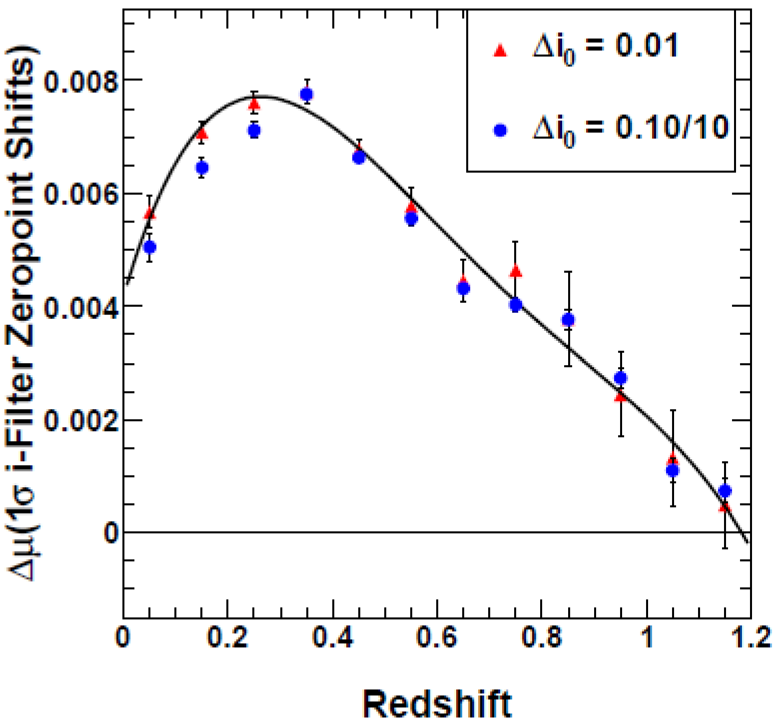
- Mini-DeCam (PreCam) survey grid data from late 2010-early 2010 (using 2 DECam CCDs and mini-filters) , to produce standards for DECam (hit PreCam field every 20-30 mins)
- Still need a nearby anchor for best cosmology

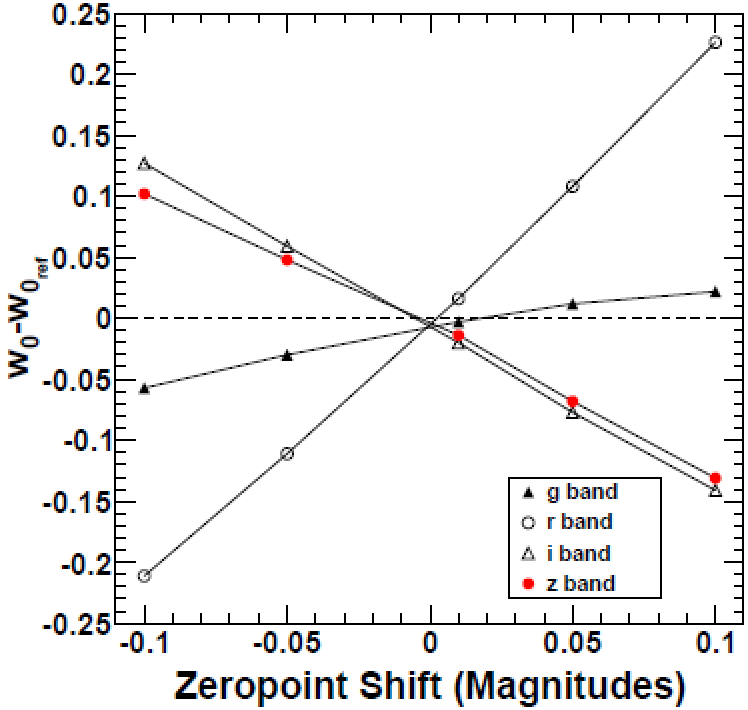


# DES SN Survey Basics and Simulation Studies



# DES SN Survey Basics and Simulation Studies



# DES SN Survey Basics and Simulation Studies

| DES SNIa Data Set | DETF FoM (Stats.) |
|---|---|
| Hybrid 10-field | 228 |
| Hybrid 5-field (MLCS2k2) | 225 |
| Hybrid 5-field (SALT2) | 200 |
| Shallow 9-field | 218 |
| Deep 3-field | 214 |

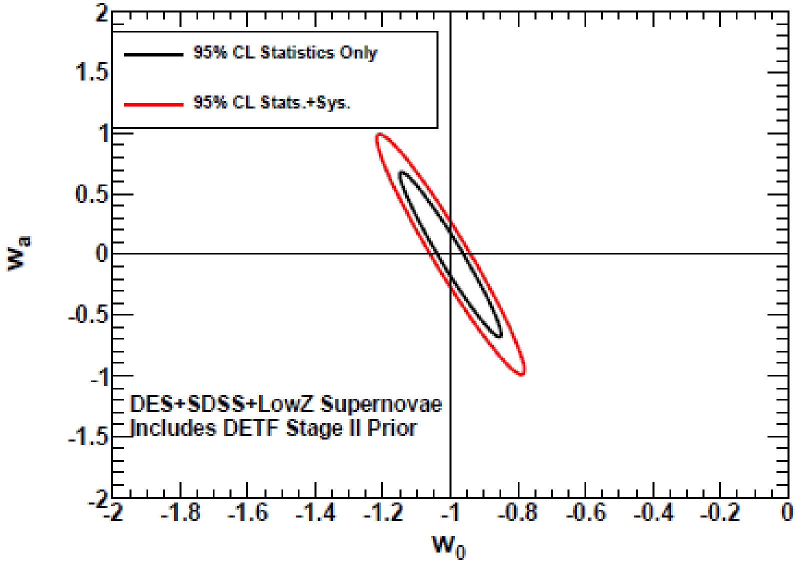
Table 14:: Dark Energy Task Force Figure-of-Merit for four of the DES SN survey strategies considered (see Tab. 3) using statistical uncertainties only. Each survey is augmented by a projected low-redshift SNIa anchor and a simulated 3-year SDSS SNIa data set. The number of SNIa in each survey is also trimmed based on the host galaxy fractions in table 7. The Figure-of-Merit before trimming is typically 15 units larger.

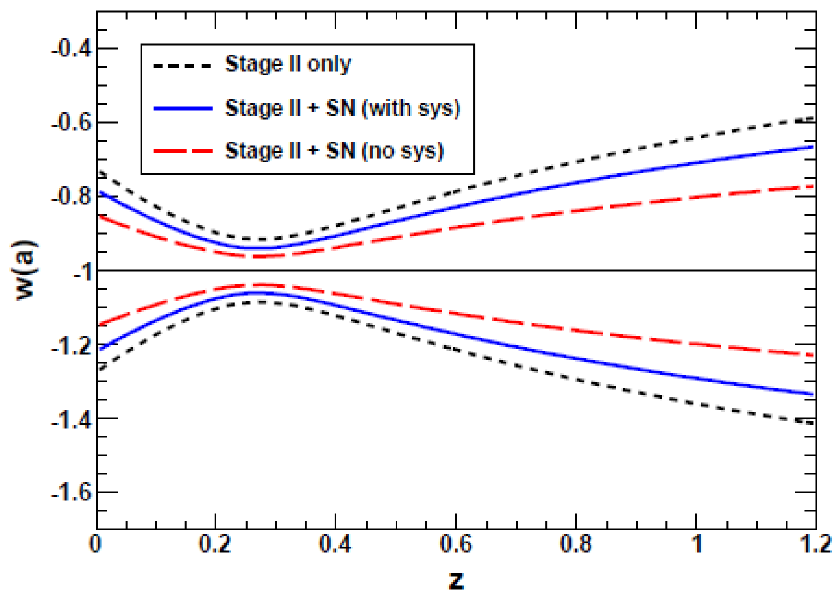
| Systematic change included | FoM with systematic |
|---|---|
| Filter zeropoint shift | 157 |
| Intercalibration | 188 |
| Filter $\lambda$ shift | 179 |
| Core collapse mis-id. | 226 |
| Dust prior $R_V$ and $\tau_{AV}$ | 128 |
| Total without dust prior | 124 |
| Total with dust prior | 101 |

Table 15:: DETF FoM including various systematic changes in the DES SNIa hybrid 10-field survey (including a low-redshift anchor and a simulated SDSS sample). The systematic changes for the hybrid 5-field survey are very similar.

**Doesn't include dust type evolution, light curve model sys., intrinsic SN colors confusion, …**

# DES SN Survey Basics and Simulation Studies

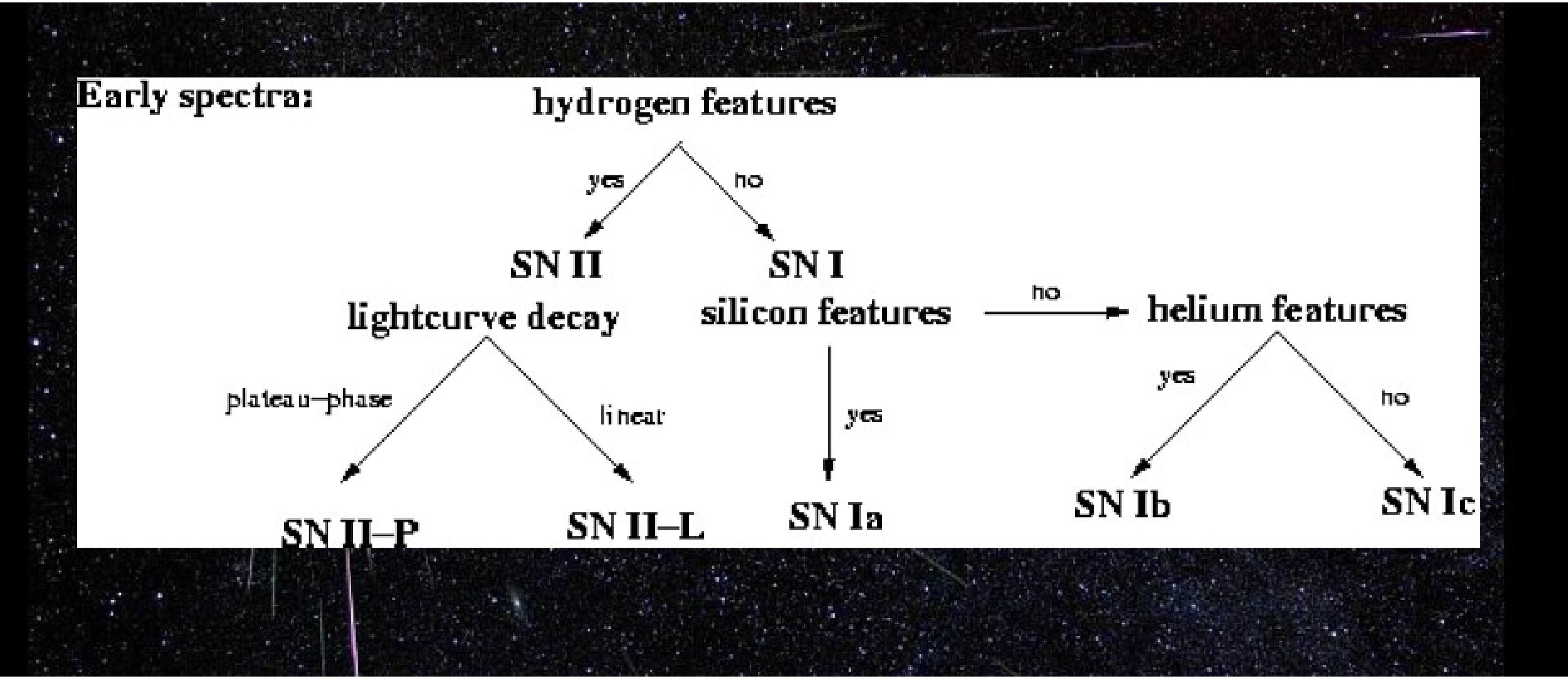


# Union 2.1 SN systematics

| Source | Error on Constant $w$ |
| --- | --- |
| Vega | 0.033 |
| All Instrument Calibration | 0.030 |
| (ACS Zeropoints) | 0.003 |
| (ACS Filter Shift) | 0.007 |
| (NICMOS Zeropoints) | 0.007 |
| Malmquist Bias | 0.020 |
| Color Correction | 0.020 |
| Mass Correction | 0.016 |
| Contamination | 0.016 |
| Intergalactic Extinction | 0.013 |
| Galactic Extinction Normalization | 0.010 |
| Rest-Frame $U$-Band Calibration | 0.009 |
| Lightcurve Shape | 0.006 |
| *Quadrature Sum of Errors/ Sum of Area (not used)* | *0.061* |
| Summed in Covariance Matrix | 0.048 |

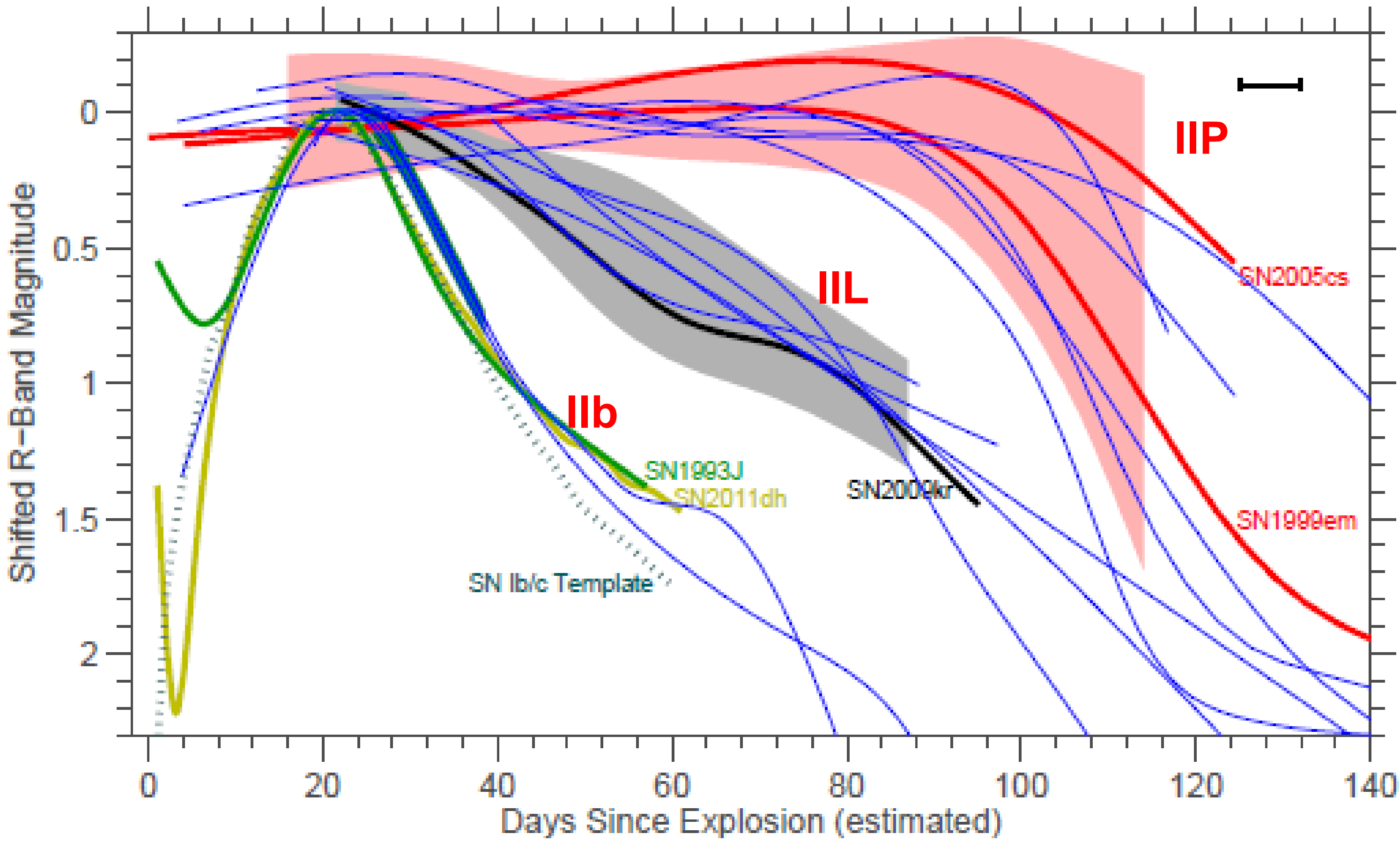
**Core collapse contamination**


Early spectra:
hydrogen features
yes
no
SN II
SN I
lightcurve decay
silicon features
no
helium features
plateau–phase
linear
yes
yes
no
SN II–P
SN II–L
SN Ia
SN Ib
SN Ic

CALTECH CORE-COLLAPSE PROJECT (CCCP) OBSERVATIONS OF TYPE II SUPERNOVAE: EVIDENCE FOR THREE DISTINCT PHOTOMETRIC SUBTYPES

Iair Arcavi[1,2], Avishay Gal-Yam[1], S. Bradley Cenko[3], Derek B. Fox[4], Douglas C. Leonard[5], Dae-Sik Moon[6], David J. Sand[7,8], Alicia M. Soderberg[9], Michael Kiewe[10], Ofer Yaron[1], Adam B. Becker[3], Raphael Scheps[11], Gali Birenbaum[12], Daniel Chamudot[13] and Jonathan Zhou[14]

*Draft version June 12, 2012*



# Type Ia Supernovae Selection and Forecast Cosmology Constraints for the Dark Energy Survey

E. Gjergo,[a,b] J. Duggan,[c] J. D. Cunningham,[c,a] S. Kuhlmann,[a]
R. Biswas,[a] E. Kovacs,[a] J. P. Bernstein[a] H. Spinka[a]

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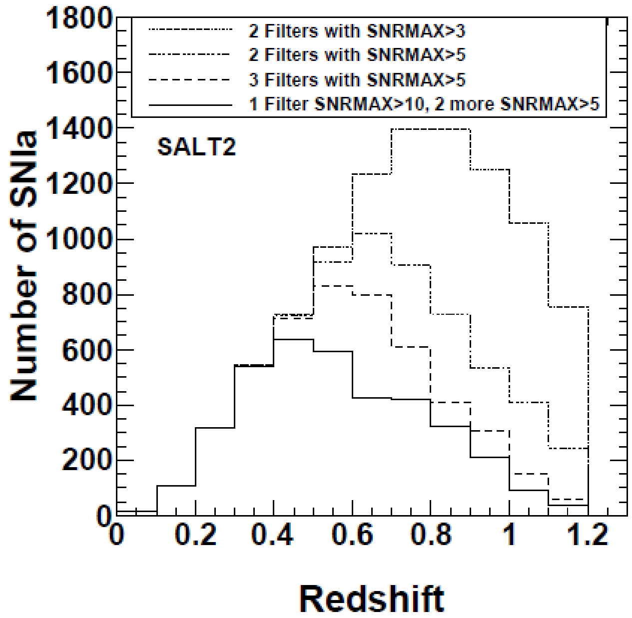
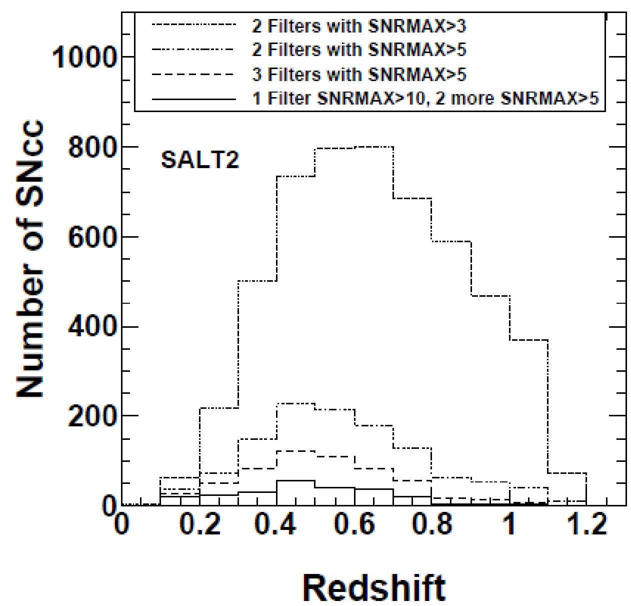
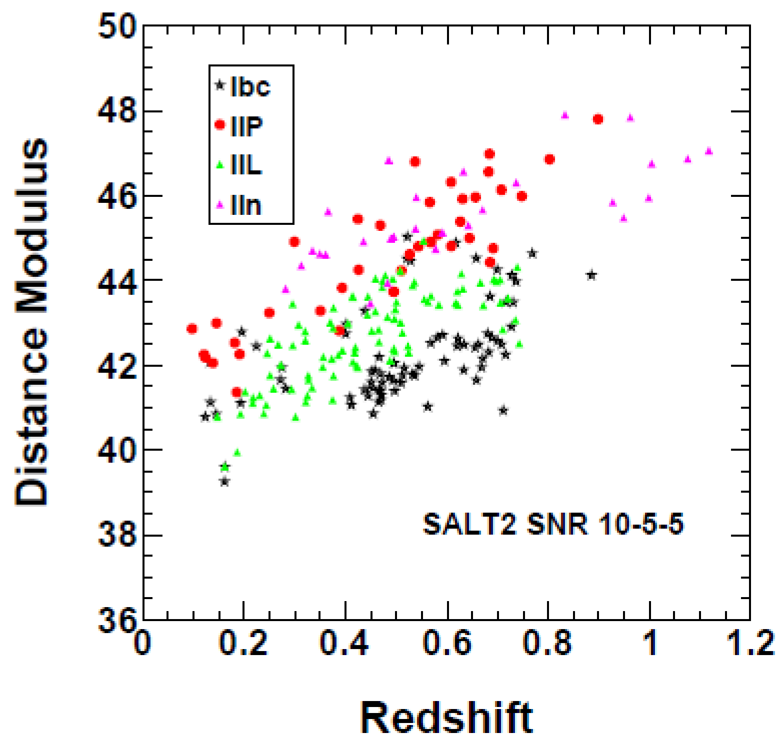
kuhlmann@anl.gov, kovacs@anl.gov, rbiswas4@gmail.com

**Abstract.** We present the results of a study of selection criteria to identify Type Ia supernovae photometrically in a simulated mixed sample of Type Ia supernovae and core collapse supernovae. The simulated sample is a mockup of the expected results of the Dark Energy Survey. Fits to the `MLCS2k2` and `SALT2` Type Ia supernova models are compared and used to help separate the Type Ia supernovae from the core collapse sample. The Dark Energy Task Force Figure of Merit (modified to include core collapse supernovae systematics) is used to discriminate among the various selection criteria. This study of varying selection cuts for Type Ia supernova candidates is the first to evaluate core collapse contamination using the Figure of Merit. Different factors that contribute to the Figure of Merit are detailed. With our analysis methods, both `SALT2` and `MLCS2k2` Figures of Merit improve with tighter selection cuts and higher purities, peaking at 98% purity.




**Competition between increasing Ia statistics and effect on distance modulus due to core collapse.**

**In this study, purity is most important impact on cosmology. Best purity ~98%.**

- Type Ia SNe Light Curves
- SALT2  Light Curve Model Basics
- Union 2.1 Sample (SCP)  plots not in their paper or their web page
- Cosmology Fit Results vs Priors   (and systematics)
- Calibration
- Type Ia brightness correlations with host galaxy properties
- Type Ia Progenitor Systems
- Dust
- UV problem
- Evolution with redshift/conclusions
- Dark Energy Survey  SNe Cosmology optimization
- Core Collapse SNe contamination of photometric samples